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REEXAMINATION OF HIBSCHITE

A. PABST,
University of California, Berkeley, California.

ABSTRACT

X-ray powder patterns of hibschite from the type locality at Aussig, Bohemia, closely resemble patterns of grossularite and plazolite. This confirms the suggestion of Belyankin and Petrov that it is nearly identical with plazolite. The conclusion is inescapable that hibschite does not have the composition usually assigned to it.

INTRODUCTION

Hibschite was discovered by Cornu[1] as octahedral mantles about minute fragments of garnet in inclusions in phonolite at Marienberg, near Aussig, Bohemia. Cornu also identified dodecahedral mantles about melanite from Aubenas, Vivarais, France, previously called garnet by Lacroix,[2] as "hibschite." Cornu was unable to separate hibschite from its associated minerals, especially the enclosed garnet, for analysis. Instead he tried to determine its composition by analyzing it together with the enclosed kernels of garnet and deducting from this bulk analysis the composition of the kernels which were also analyzed separately. In this way he derived a formula for hibschite identical with that of lawsonite, and it has since been assigned this formula in innumerable text- and reference books. A year later Cornu[3] found hibschite at a similar locality, the Mädstein, near Neschwitz, Bohemia, but obtained no further information on its composition.

Hibschite was next reported by Belyankin and Petrov,[4] again as mantles about garnet, from a marl and teschenite contact near Nikortzminda, Georgia. For the hibschite they found $n_{Na} = 1.681$ and $G. = 3.06$, and for the enclosed garnet $n = 1.815$ and $G. = 3.68$. No analysis was given.

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[1] Cornu, F., Hibschit, ein neues Kontaktmineral: *Tschmermak's min., pet. Mitt.*, **25**, 249–268 (1906).

[2] Lacroix, A., Les enclaves des roches volcaniques, 149 (**1893**).

[3] Cornu, F., Ueber einen Kontakt zwischen Phonolith und oberturonem Kreidemergel am Mädstein bei Neschwitz a. d. Elbe: *Tschermak's min., pet. Mitt.*, **26**, 457–468 (1907).

[4] Belyankin, D. S., and Petrov, V. P., Hibschite in Georgia: *Comptes Rendus* (*Doklady*) *de l'Academie des Sciences de l'URSS*, **24**, no. 4, 349–352 (1939).

Belyankin and Petrov also examined some of the hibschite from Aussig, Bohemia, and reported that the index of the enclosed garnet varies from 1.815, at the core, to 1.808 at the rim, and that its specific gravity is 3.61. They obtained no new data on the properties of the original hibschite but they reviewed Cornu's analyses and showed that they are not in harmony with the properties of the hibschite and the enclosed garnet.

Later Belyankin and Petrov[5] reported analyses of hibschite concentrates from which they derived the formula, $3CaO \cdot Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$. This is the same formula as that used for plazolite by the writer[6] in his work on the crystal structure of that mineral. Belyankin and Petrov concluded that hibschite and plazolite are both members of the same mineral group for which they proposed the name *grossularoid group* because of the established close relationship of plazolite and grossularite.[7] Incidentally they reported another locality for "grossularoid", the fifth or sixth, in the Lopan gorge, southern Osetia, Transcaucasia.

In the main the writer is in accord with the conclusions of Belyankin and Petrov, but certain apprehensions they express concerning the relations of plazolite and hibschite require comment. They state that "plazolite differs only by a small and rather variable content of CO_2," and in a foot-note, "the role of CO_2 in plazolite is not quite clear." In my work on the structure of plazolite, I disregarded the CO_2 content shown in the analyses. Soon thereafter I received some extended comments from Foshag, who had made the analyses, ending in the statement "the CO_2 was in all probability due to admixture."[8] Belyankin and Petrov are also concerned about "the fact that plazolite is of a somewhat yellowish color" since iron oxides are absent in the analysis. Actually it was described by Foshag[9] as "colorless to light yellow." Such faint color as appears in some plazolite certainly does not indicate the presence of any important amounts of coloring constituents.

In Table 1 are given the analyses of plazolite from Crestmore and hibschite from Nikortzminda for comparison with the ideal analysis corresponding to the formula assigned to these materials. It is seen that the hibschite analysis agrees fairly well if ferric oxide is grouped with alumina.

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[5] Belyankin, D. S., and Petrov, V. P., The grossularoid group (hibschite, plazolite): *Am. Mineral.*, **26**, 450–453 (1941).

[6] Pabst, A., The crystal structure of plazolite: *Am. Mineral.*, **22**, 861–868 (1937).

[7] Recently the name *garnetoid* has been similarly used by Duncan McConnell, *Am. Mineral.*, **27**, 452–461 (1942).

[8] Personal communication from W. F. Foshag, dated July 23, 1937.

[9] Foshag, W. F., Plazolite, a new mineral: *Am. Mineral.*, **5**, 183–185 (1920).

TABLE 1

	I	II	III
SiO_2	27.57	25.71	28.18
TiO_2	0.67	—	—
Al_2O_3	18.52	25.27	23.91
Fe_2O_3	3.70	—	—
FeO	0.15	—	—
MnO	0.08	—	—
CaO	38.39	39.75	39.46
MgO	2.13	trace	—
H_2O-	0.29	9.27	8.45
H_2O+	8.55		
	100.00	100.00	100.00

I. Hibschite, Nikortzminda, Georgia, Belyankin and Petrov, *Am. Mineral.*, **26,** 451 (1941).

II. Plazolite, Crestmore, California, recalculated from Foshag's analysis III, *Am. Mineral.*, **5,** 184 (1920), after deducting for admixed calcite indicated by the presence of CO_2.

III. Composition corresponding to $3CaO \cdot Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$.

MATERIAL USED

Since Belyankin and Petrov had merely cast doubt on the composition assigned to the original hibschite by Cornu, but contributed nothing to establish its composition or structure, and since it was reported by Cornu to be octahedral, in contrast to the dodecahedral habit of plazolite which is to be expected of a "grossularoid," it seemed desirable to the writer to reexamine the original hibschite with a view of obtaining certainty in these matters. Through the courtesy of Dr. Foshag two specimens of hibschite from Bohemia were borrowed from the collections of the United States National Museum.

All observations were made on a specimen labeled (USNM) "95150 Hibschite microscopic crys. in enclosure of chalk-marl in phonolite. Aussig, Bohemia, Czecho-slovakia." It consists of several small fragments of pale-colored marl corresponding closely to the description given by Cornu. Even with a hand lens it is not possible to discern any hibschite. The material to be studied was separated by prolonged leaching with cold, highly diluted, acetic acid, as described by Cornu. This tends to separate the hibschite which is not attacked by such acid from the associated calcite and zeolites. Supplementing this treatment with light crushing, bromoform separation and prolonged picking under a binocular microscope, concentrates of hibschite, containing several hundred crystals each, were made from two of the marl fragments. No differences were found in the appearance or properties of the hibschite in the two concentrates. Comparison of Cornu's drawing of hibschite, reproduced in the upper part of Fig. 1, with photomicrographs of crystals separated by the writer as described, shown in the lower part of Fig. 1, will leave no doubt that this is the material named hibschite by Cornu.

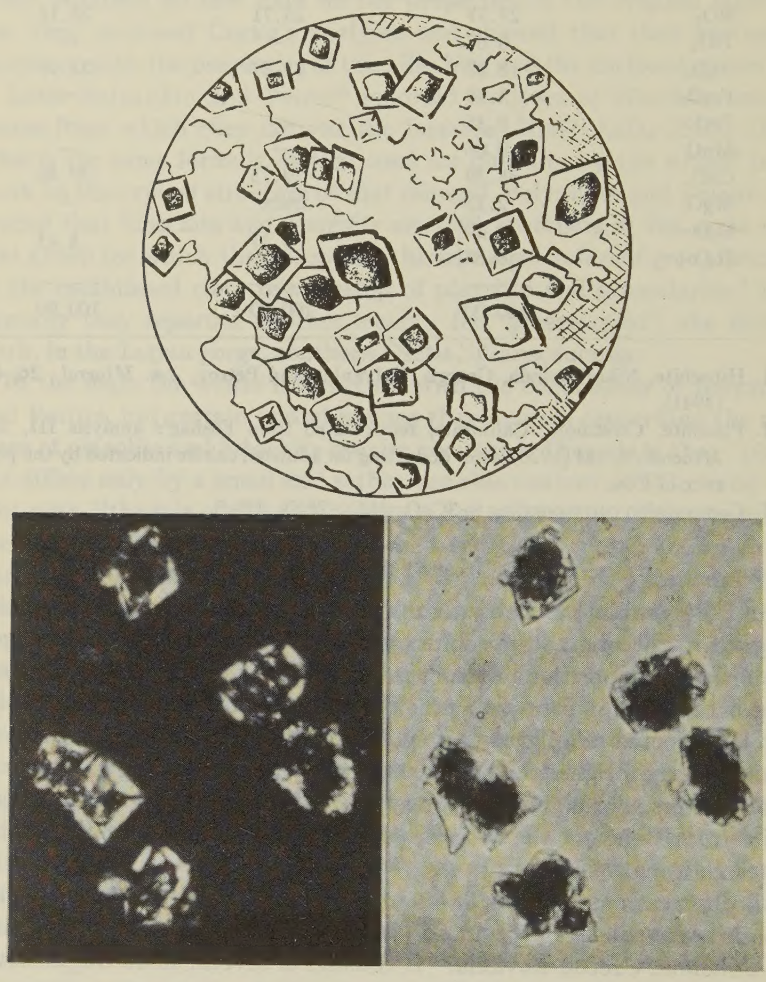

FIG. 1. Top: Cornu's Fig. 1, *Tsch. min., pet. Mitt.*, **25**, 256 (1906). Bottom: Hibschite crystals from Aussig, Bohemia, USNM 95150, in resin of $n=1.67$. Width of field 0.315 mm. Left, crossed nicols; right, same grains, nicols not crossed.

It was not possible to separate enough hibschite for a new analysis and besides all crystals showed cloudy nuclei of garnet from which they could not be separated. For this reason also it was impossible to determine satisfactorily the density of hibschite. The mixed grains, whose dimensions do not exceed 0.08 mm., were immersed in thallium formate solution and found to remain in suspension when the specific gravity of the solution was adjusted to 3.2–3.3. This is not in conflict with the reported specific gravities of hibschite and of the nuclei, but it does not exclude the possibility that the specific gravity of hibschite may be somewhat higher than 3.05, the figure reported by Cornu.

The thickness of the hibschite mantles varies greatly, but the mixed grains are always over half hibschite, and where the thickness of the mantle is about the same as the radius of the nucleus, as it is in many cases, the hibschite would constitute about seven-eights of the volume of the grain.

The hibschite mantles are always quite clear and colorless, and show a slight birefringence, noted by Cornu, with a constant "quadrant structure," the vibration direction of the high index ray always being normal to the octahedral edges. Observation on many grains showed that the refractive index of the hibschite mantle is always about 1.69. This is considerably different from the value, 1.67, reported by Cornu, but only slightly higher than the values, 1.681 and 1.686, reported by Belyankin and Petrov for hibschite from near Nikortzminda, and from the Lopan gorge.

The garnet nuclei are all rather clouded and rough. Only a few grains were suitable for determination of the refractive indices of these nuclei. They were in all cases well below the index of methylene iodide saturated with sulphur. The mean index of these grains is probably of the order of 1.76–1.77. This is far below the value reported by Belyankin and Petrov, cited above. It would correspond to the index of garnets of composition about $Gr_{80}And_{20}$, which are well known, whereas the indices reported by Belyankin and Petrov would correspond to $Gr_{53}And_{47}$, an unlikely composition, or to a garnet of the Alm-Sp series which is not in harmony with the specific gravity of the material, the paragenesis, or the x-ray observations reported below. The garnet is certainly not melanite as stated by Cornu.

X-RAY EXAMINATION

Through the kindness of Mr. W. H. Dore of the Division of Plant Nutrition, College of Agriculture, University of California, the writer obtained an x-ray powder pattern of the hibschite with garnet nuclei. The 22 measurable lines of the powder pattern are recorded in Table 2. They

TABLE 2. POWDER PATTERN OF HIBSCHITE FROM NEAR AUSSIG, BOHEMIA.
(USNM specimen 95150)

Mo-K$_\alpha$ radiation; cassette radius, 8 inches.

Intensity	$\sin^2\theta$	$(h^2+k^2+l^2)\times Q$	*hkl*
VW	0.00526	6×0.000877	211
S	0.01399	16×0.000875	400
VS	0.01741	20×0.000871	420
W	0.01915	22×0.000871	332
M	0.02093	24×0.000873	422
M-W	0.02268	26×0.000873	431
M	0.02623	30×0.000874	521
VW	0.02791	32×0.000872	440
M-S	0.03321	38×0.000874	611, 532
VW	0.03517	40×0.000879	620
M	0.04210	48×0.000877	444
M-S	0.04556	52×0.000876	640
S	0.04895	56×0.000874	642
M	0.05589	64×0.000874	800
M	0.06967	80×0.000871	840
M	0.07350	84×0.000875	842
W	0.07732	88×0.000879	664
VW	0.08607	98×0.000878	853, 941
W	0.10111	116×0.000872	10·4·0, 864
W	0.10562	120×0.000880	10·4·2
W	0.11264	128×0.000880	880
W	0.13432	152×0.000883	10·6·4

Average value of Q, 0.0008753
$a_0=12.00\pm0.02$ Å
VW very weak, W weak, M medium, S strong, VS very strong.

indicate an isometric body-centered cell with cube edge 12.00±0.02 Å. This dimension is intermediate between those of the grossularite, plazolite and andradite cells, listed in Table 4.

Two phases are definitely present in this material, but all the lines of the powder pattern can be interpreted on the basis of one lattice and there is no indication (see Fig. 2) of the broadening or doubling of lines to be expected if two garnet-like materials of different cell dimensions were present. Hence it seems that the two phases have nearly the same cell dimensions.

The photometer curves of Fig. 2 show that the hibschite pattern is very similar to the patterns of plazolite and grossularite. In each case the high peak towards the right corresponds to (420) and the peak farthest to the left to (941) (853).

The slight intensity differences of plazolite and grossularite were dis-

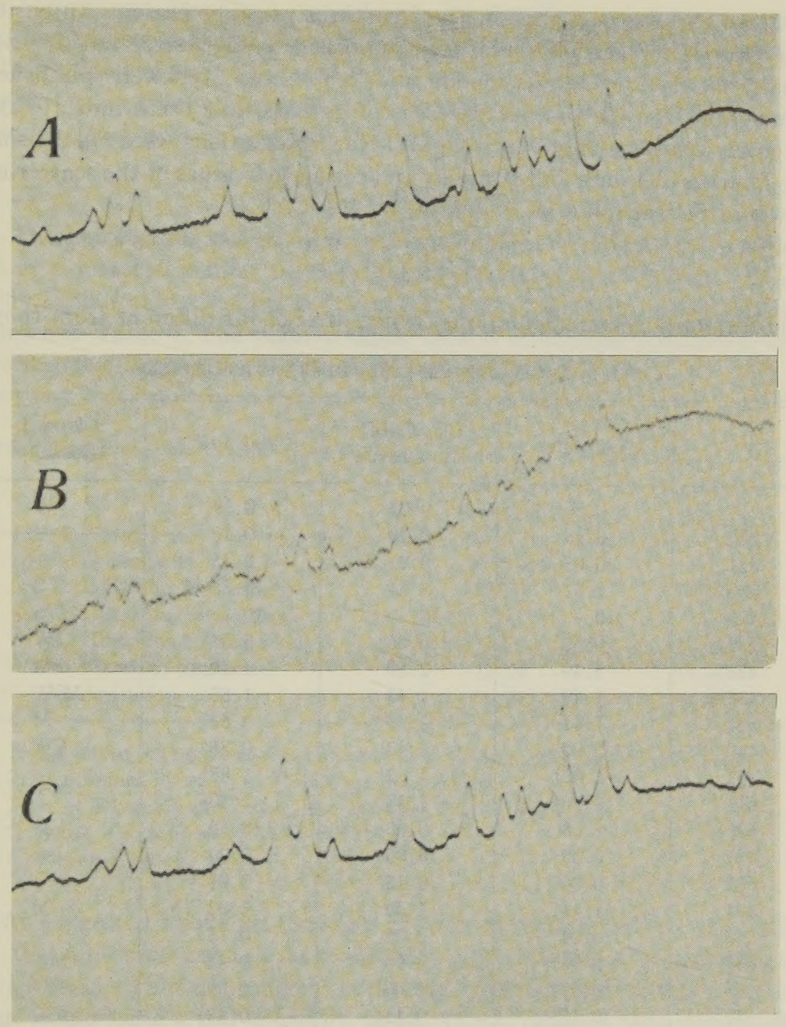

FIG. 2. Photometer curves of x-ray powder patterns. A—Grossularite, Georgetown, California; B—Hibschite, Aussig, Bohemia; C—Plazolite, Crestmore, California.

cussed by the writer[10] and it was shown that they can be accounted for by the structure proposed for plazolite. Close inspection of the photometer curves will show that the hibschite pattern shows intensity relations similar to, but not just like, either grossularite or plazolite. The most characteristic feature of the plazolite pattern, the small peaks for (211) and (321) at the right, is scarcely discernible in the hibschite pattern.

These observations can only be interpreted by a comparison with intensities to be expected from the structures possibly present. Intensity calculations for garnets have been published by Menzer,[11] but are not wholly satisfactory because he did not use f curves. Stockwell[12] published nomograms for the powder patterns of garnets, but these indicate the intensity relations only very roughly. New calculations were made using the f curves of James and Brindley and estimated values of the scattering power of Fe''' as follows:—

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[10] *Op. cit.*

$10^{-8} \times \sin\theta/\lambda$	0.0	0.1	0.2	0.3	0.4
f_0—Fe'''	23.0	21.3	17.9	14.9	12.6

The results of these calculations, which are not far different from those

TABLE 3. INTENSITIES OF LINES IN POWDER PATTERNS.

		*Calculated**		*Observed*
	Andradite	Grossularite	Plazolite	Hibschite
211	0.00	0.02	0.39	VW
220	0.26	0.10	0.10	—
321	0.03	0.22	0.45	—
400	7.82	3.34	4.55	S
420	10	10	10	VS
332	0.55	0.86	0.34	W
422	5.49	2.59	1.40	M
431	1.49	1.42	1.85	M-W
521	1.41	1.73	2.62	M
440	0.00	0.42	0.38	VW
532	1.07	1.02	1.88	M-S
611	1.20	1.58	2.10	
620	1.68	0.00	0.59	VW
541	0.00	0.00	0.00	—
631	0.00	0.13	0.01	—
444	1.11	1.59	2.02	M
543	0.04	0.28	0.13	—
640	2.95	3.98	2.91	M-S
633	0.07	0.00	0.09	—
552	0.17	0.15	0.43	
721	0.00	0.00	0.00	
642	9.76	4.90	5.50	S
651	0.07	0.05	0.28	—
732	0.02	0.01	0.00	
800	2.16	1.38	1.58	M

* Calculated intensities are on the basis of I_{420} taken as 10, this being the strongest line for all these materials in the range covered.

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[11] Menzer, G., Die Kristallstruktur der Granate: *Zeits. Krist.*, **69**, 300–396 (1928).

[12] Stockwell, C. H., An x-ray study of the garnet group: *Am. Mineral.*, **12**, 327–344 (1927).

of Menzer and Stockwell just referred to, are given in Table 3 together with the observed intensities on hibschite. It is clear from a comparison of the observed and calculated intensities that there cannot be any large contribution from an andradite (melanite) constituent, since this would require much greater intensity of (620) and other differences.

INTERPRETATION

All observations can be fairly well reconciled by considering hibschite to be a material similar to plazolite, as proposed by Belyankin and Petrov. This would account for the values of the cell constants and indices shown in Table 4. The slightly higher indices of hibschite doubtless arise from such differences in composition as are shown in Table 1.

TABLE 4.

	Lattice Constant	Refractive Index
1. Grossularite	11.840Å	1.735
2. Hibschite, Marienberg	12.00	1.69
3. Hibschite, Lopan gorge	—	1.686
4. Hibschite, Nikortzminda	—	1.681
5. Plazolite, Crestmore	12.14	1.675
6. Andradite	12.045	1.895

1. Values for pure grossularite, Fleischer, *Am. Mineral.*, **22**, 751–759 (1937).
2. Determined by writer on USNM specimen 95150.
3 and 4. Belyankin and Petrov, *Am. Mineral.*, **26**, 450–453 (1941).
5. Pabst, *Am. Mineral.*, **22**, 861–868 (1937).
6. Fleischer, *op. cit.*

As suggested above on the basis of their refractive indices, the nuclei of the hibschite crystals are probably grossularite of a composition $Gr_{80}And_{20}$, within the range of known garnets. Garnets of this composition would have a cell constant, about 11.9Å, close to that determined from the hibschite pattern. The difference, 0.1Å, is insufficient to produce doubling or even marked broadening of the lines, especially since the hibschite portion probably makes up three fourths or more of the diffracting substance.

CRYSTAL HABIT

Though no crystals of hibschite or plazolite have ever been found that are large enough for measurement, it is possible to determine the very simple forms without any doubt under a binocular microscope. Plazolite, like many garnets, shows dodecahedrons only. Hibschite, on the other hand, shows only octahedrons when the crystals are really well developed about small nuclei as at Marienberg, Nikortzminda, and the Lopan gorge. Only where it forms very thin crusts over dodecahedral nuclei, as at Mädstein and in some specimens from the Lopan gorge, is its outline dodecahedral, but in these cases the form must be largely controlled by the nuclei.

Crystals of garnet-like structure and octahedral habit are definitely anomalous. The reexamination of hibschite has revealed nothing to explain this anomaly.

POTASH-OLIGOCLASE IN HAWAIIAN LAVAS*

GORDON A. MACDONALD, *U. S. Geological Survey,*
333 Federal Bldg., Honolulu, Hawaii.

ABSTRACT

Interstitial feldspar in Hawaiian lavas with the refractive indices of oligoclase or andesine has an abnormally small positive optical angle. The abnormalities have previously been attributed to an isomorphous admixture of nepheline or carnegieite, but this is made doubtful by the discovery of the material in rocks with normative quartz. It is concluded that the abnormal properties are caused by an admixture of potash feldspar, the compound being unstable at ordinary temperatures but prevented from unmixing by the rapid cooling of the enclosing rocks.

INTRODUCTION

Many Hawaiian lavas contain feldspar which differs notably in some of its optical properties from any commonly recognized variety. This feldspar was first described by Barth, who found it widely distributed in Hawaiian lavas.[1] Its properties, as described by Barth, include a range of refractive index generally between 1.53 and 1.55, and a positive optic angle ranging as low as 10°. Observations by the writer are in close agreement with those of Barth. The mineral commonly has refractive indices within the range of oligoclase and sodic andesine, and $+2V$ varying from large to nearly uniaxial. The estimated optic angle may show a range of 20° or more in different grains in the same thin section.

This peculiar feldspar was found by Barth in lavas in which nepheline is present in the norm, but not in the mode. He concluded, as a result of calculations of its theoretical composition based on the chemical and modal analyses, that it is a soda-lime feldspar containing a variable isomorphous admixture of alkali feldspar and nepheline, the latter probably in the form of carnegieite. On the basis of its apparent nepheline content, he suggested its identity with anemousite, a feldspar containing nepheline which had previously been described from the island of Linosa.[2] It has recently been doubtfully identified by Stark and Howland in lavas from Borabora.[3]

Identical feldspar from basaltic lavas of Japan and neighboring parts of the Asiatic mainland has been described by Tomita,[4] who concluded that it is a potash-rich, high-temperature variety of andesine.

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* Published by permission of the Director, Geological Survey, United States Department of the Interior.

[1] Barth, T. F. W., Pacificite, an anemousite basalt: *Jour. Washington Acad. Sci.*, **20,** 60–68 (1930); Mineralogical petrography of Pacific lavas: *Am. Jour. Sci.*, 5th ser., **21,** 401–402, 510–513 (1931).

[2] Washington, H. S., and Wright, F. E., A feldspar from Linosa and the existence of soda anorthite (carnegieite): *Am. Jour. Sci.*, 4th ser., **29,** 52–70 (1910).

[3] Stark, J. T., and Howland, A. L., Geology of Borabora, Society Islands: *B. P. Bishop Mus., Bull.* **169,** 34 (1941).

OCCURRENCE OF THE FELDSPAR

In Hawaiian lavas, the anomalous feldspar is largely confined to the interstices of the groundmass. Nearly all phenocrysts and most of the groundmass feldspar appear to be entirely normal soda-lime plagioclase. The anomalous feldspar is generally absent in rocks with a glassy base, presumably being retained in the glass. Thus in most rocks, it is restricted to the portion that crystallized last. The percentage is generally small, ranging from 2 or 3 to 15 or 20 per cent, the amount being typically greater in rocks of basaltic andesite or andesite composition than in the basalts. In many basalts it is entirely absent.

In a few andesites a large proportion of the feldspar grains exhibit abnormal properties. This is true of the andesite constituting White Hill, on the edge of the summit depression of Haleakala volcano, in which most of the feldspar shows a positive sign and an optic angle estimated at 45° to 55°, combined with refractive indices in the range of sodic andesine and calcic oligoclase. A chemical analysis of this rock is reproduced as number 15 in the accompanying table, and a micrometric analysis yields the following modal composition: feldspar 62.3%, monoclinic pyroxene 19.8%, olivine 7.5%, and magnetite 10.4%. In rocks which contain large amounts of the abnormal feldspar, the optic angles appear to be larger, and the deviation from normal therefore less extreme, than in many rocks containing less of the material.

Typical of the Hawaiian basaltic andesites is a lava collected in Hanawi Gulch, on the northern side of Haleakala volcano. It is aphyric, with an intergranular texture, and is composed of calcic andesine, 30%; interstitial feldspar with the refractive indices of calcic oligoclase, 20%; monoclinic pyroxene, 25%; olivine, 5%; magnetite, 20%; and a few minute needles of apatite. The interstitial oligoclase has a positive axial angle estimated from optic axis and bisectrix figures to range from 10° to 50°. Its refractive indices determined by immersion are: $\alpha = 1.545$, $\beta = 1.547$, $\gamma = 1.550$ ($\pm .003$). Although the estimated optic axial angles may be in error possibly by as much as 10°, it is obvious that the values are abnormally low for feldspar with these refractive indices.

In its usual interstitial occurrence, the anomalous feldspar is anhedral and untwinned. A few grains show poor cleavage. The extinction is frequently irregular or undulatory.[5] The birefringence is low, estimated as between 0.004 and 0.008. A few grains show carlsbad or albite twinning, but twinning is rare. The mineral is generally anhedral and contains numerous inclusions of all the other minerals, showing that it was the last constituent to crystallize. Especially characteristic are very abundant included highly acicular, minute crystals of apatite.

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[4] Tomita, T., Geological and petrological study of Dogo, Oki, part 12 (in Japanese): *Jour. Geol. Soc. Tokyo.*, **38,** 413 (1931); Olivine-trachyandesitic basalt from Hsueh-hua-shan Hill, Ching-hsing District, North China: *Jour. Shanghai Sci. Inst.*, sec. 2, **1,** 1–10 (1933).

EFFECT OF OVERLAPPING GRAINS

Sugi has recently described soda-lime feldspar with apparent small positive optic angle in olivine dolerite from Fu-shun, in Manchuria.[6] He clearly demonstrates that in this material the abnormal properties of the feldspar are caused by the superposition of two thin plates of feldspar. The plates are approximately parallel to 010, and their combination is probably the result of twinning on the carlsbad or albite law. The feldspar is sodic labradorite or calcic andesine. Crystals are commonly found to consist of two parts in which the orientation of the X vibration directions are nearly opposite. The abnormal properties are restricted to certain areas within the crystals in which the two parts of contrasted optic orientation overlap, and they are shown to be the result of the partial compensation of the double refraction in one layer by the other layer of nearly opposite orientation.

As the result of special search similar occurrences have been found in a few Hawaiian lavas. In the specimen from Molokai (no. 13, in the table), certain low-birefringent zones in phenocrysts have been found to have small optic angle although the rest of the crystal appears normal. In these instances the crystal consists of two parts, in which the directions of the faster ray are nearly opposite. However, in the same rock the groundmass feldspars, many of which also have a small optic angle, show no evidence of being compound. The same is true in most of the Hawaiian lavas which contain the anomalous feldspar. Owing to the smallness of many of the grains, an overlap of one over another is common, but no regular relationship between the overlapping flakes is detectable. Their optic orientations are haphazard with regard to one another. Moreover, there is frequently no evidence of an overlapping condition, the grains with small 2V appearing to be single homogeneous crystals. Twinning, on the carlsbad and especially on the albite law can rarely be recognized. Irregular or undulatory extinction, which is typical of these feldspars, might, and undoubtedly in part does, result from the irregular overlapping of the thin flakes, but it might also, as in the quartz of many granitic rocks, be the result of the strains set up in the last crystallized minerals which are forced to adjust themselves to the residual spaces between the earlier-crystallized grains. Moreover, the clearest conoscopic figures are generally obtained on grains which show the most regular extinction and no evidence of overlap of one grain by another, suggesting that the abnormally small optic angle is unrelated to either overlap or strain.

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[5] Macdonald, G. A., Petrography of Kahoolawe, in Stearns, H. T., Geology and groundwater resources of the islands of Lanai and Kahoolawe, Hawaii: *Hawaii Div. of Hydrography, Bull.*, **6**, 151–153 (1940).

[6] Sugi, Ken-ichi, On the nature of some plagioclase apparently with small optical angle, with special reference to the plagioclase in olivine-dolerite from Fu-shun, Manchuria: *Kyushu Imp. Univ., Fac. Sci. Mem., ser. D*, **1**, 1–22 (1940).

The possibility that the abnormal properties of the groundmass feldspars are due to superimposed plates with contrasted optic orientation is difficult to rule out entirely, but in view of the above facts is regarded as very unlikely.

EVIDENCE FROM CHEMICAL ANALYSES

In the accompanying table are shown the chemical and normative compositions of 15 Hawaiian lavas, all of which contain feldspar exhibiting the abnormal properties described above. The analyses are arranged in the order of increasing content of the abnormal feldspar. All have been studied microscopically by the writer, and several were described by Barth.[7] The table also shows the percentage of anomalous feldspar in the modal composition; the values quoted from Barth and several of those determined by the writer are micrometric determinations, but most by the writer are estimates. Similar estimates have been checked against micrometric determinations and found to agree within a few per cent. Reliable estimates or measurements of the amount of anomalous feldspar are difficult of attainment because of the interstitial nature of the material, the fine grain of the rocks, and the overlapping of thin grains in the groundmass. However, the figures are believed to be close enough to give valuable results. Partly glassy lavas were avoided because of the uncertainty of the composition of the glass, and because few of them contain much of the peculiar feldspar.

Barth observed the anomalous material only in rocks that contain normative nepheline, and concluded as a result of calculations of the composition of the mineral, based on the chemical and modal analyses, that the feldspar is anemousite and the abnormal properties are the result of the presence of nepheline or carnegieite. However, the writer has found the abnormal feldspar in several rocks containing normative quartz.[8] This discovery appears to rule out the presence of admixed nepheline as essential to the abnormal properties of the feldspar. Moreover, the investigations of Bowen,[9] and more recently of Dittler and Kohler,[10] indicate that only a very small amount of nepheline or carnegieite can be held in solid solution in soda-lime feldspars.

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[7] Barth, T. F. W., *op. cit.*

[8] Macdonald, G. A., *op. cit.*, p. 152.

Figure 1*A* is a graph showing the percentages of modal anomalous feldspar plotted against the percentages of normative quartz and nepheline. The distribution is essentially random, the abnormal properties being exhibited by both rocks with normative quartz and rocks with normative nepheline. There is, however, a general trend downward toward the right, which suggests a remote if not a direct control. This remote influencing factor is probably the tendency of rocks richer in normative orthoclase to be less saturated in silica than those in which normative orthoclase is less abundant. This tendency is demonstrated by a comparison of parts *A* and *B* of Fig. 1. It is concluded, therefore, that the occurrence of the abnormal feldspar is independent of the presence of nepheline. Moreover, in the Linosa feldspar described by Washington and Wright, in which admixed nepheline or carnegieite was demonstrated to exist, the measured values for the optic angle[11] are not smaller than would be expected in normal feldspar with the determined indices.[12]

If the admixture of nepheline is not the cause of the abnormal properties observed in the feldspars in Pacific lavas, it becomes necessary to seek some other factor which might be the cause. The only other component not accounted for in the modal constitution of the rocks is normative orthoclase. Consequently, in Fig. 1*B*, the percentages of abnormal feldspar have been plotted against those of normative orthoclase. A definite linear trend is immediately obvious, and is taken to indicate that an admixture of the potash feldspar molecule in the soda-lime feldspar is probably responsible for the lowering of the optic angle. The deviation of the points in the diagram from a single line is probably the result of different amounts of potash feldspar being combined with a unit amount of soda-lime feldspar. Such a variation in the amount of potash feldspar in the anomalous soda-lime feldspar would preclude the possibility of an exact linear distribution of the points in the diagram. That such a variation does occur is also suggested by the variability of the properties of the mineral, especially of the size of the optic angle. Tomita found a fairly regular decrease in the size of 2V with the decrease of the β refractive index. He suggested that the mineral might form part of a reaction

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[9] Bowen, N. L., The binary system: $Na_2Al_2Si_2O_8$ (nephelite-carnegieite)—$CaAl_2Si_2O_8$ (Anorthite): *Am. Jour. Sci.*, 4th ser., **33,** 551 (1912).

[10] Dittler, E., and Kohler, A., Über Mischkristallbildung im ternären System An-Ab-Cg: *Min. pet. Mitt.*, *Bd.* **43,** Heft 4/5 (1932). Cited by Tomita, T., *op. cit.*, p. 9.

[11] *Op. cit.*, p. 53.

[12] Winchell, A. N., Elements of Optical Mineralogy, Part 2, p. 318, New York (**1933**).

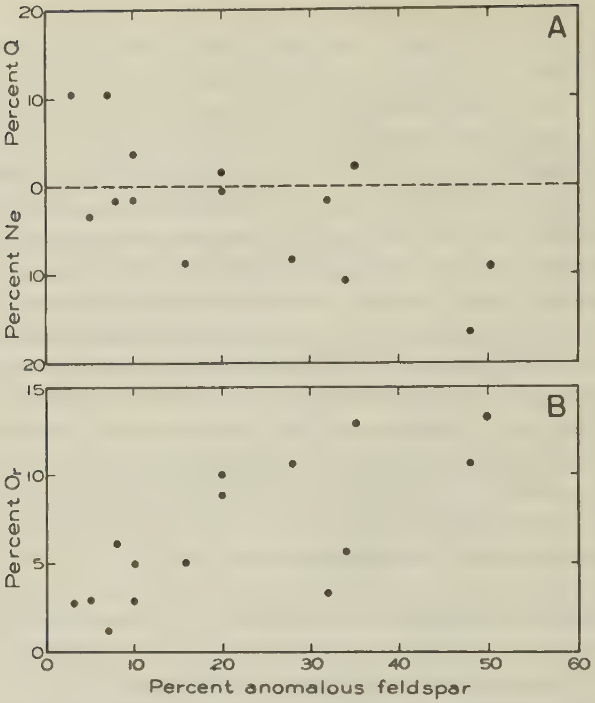

FIG. 1. Graph showing approximate percentage of modal anomalous feldspar plotted against (*A*) percentage of normative quartz and nepheline, and (*B*) percentage of normative orthoclase, in holocrystalline Hawaiian lavas.

series including potash-oligoclase, anorthoclase, and potash feldspar.[13]

Benson and Turner suggest that abnormalities in the extinction angle of certain feldspars in mugearites of the Dunedin district, New Zealand, may be due to the presence of potash feldspar in solid solution in the soda lime feldspar, but do not describe the optic angle or sign of the anomalous feldspars.[14]

EVIDENCE FROM INTRUSIVE ROCKS

The feldspar with abnormal properties appears to be restricted entirely to extrusive rocks or fine grained intrusive rocks which cooled quickly at shallow depths, or in small bodies. It has not been found in any of the coarse-grained intrusive bodies in Hawaii. Conversely, however, the gabbros contain another feldspar only very rarely encountered in the lavas. In many of these coarse-grained bodies, notably the gabbro stocks in

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[13] *Op. cit.*, pp. 8, 10.

[14] Benson, W. N., and Turner, F. J., Mugearites in the Dunedin district: *Trans. Royal Soc. New Zealand*, **70**, pt. 3, 188–199 (1940).

CHEMICAL ANALYSES OF HAWAIIAN LAVAS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SiO_2	51.77	42.99	50.12	48.59	48.00	47.06	43.28	48.27	48.78	48.04	46.43	47.19	53.14	45.46	49.55
Al_2O_3	14.33	10.21	12.35	9.83	14.12	10.26	14.43	16.52	14.18	17.95	10.91	10.95	14.60	16.18	17.78
Fe_2O_3	2.76	3.01	4.41	7.62	5.42	2.14	0.70	3.72	5.81	4.28	3.15	3.31	5.74	4.40	4.65
FeO	7.85	10.28	8.71	5.27	8.05	6.60	10.92	6.71	6.57	7.21	10.26	10.21	7.72	7.38	5.89
MgO	6.77	14.61	7.96	7.15	4.94	17.76	11.68	3.63	3.63	2.79	11.08	10.52	2.50	4.07	2.49
CaO	9.74	12.54	10.28	8.27	9.43	8.62	11.22	6.24	6.98	7.52	10.09	9.73	5.44	8.56	7.01
Na_2O	1.75	1.40	1.22	4.96	3.23	2.80	2.49	4.14	5.03	5.55	3.16	4.69	4.64	6.06	6.12
K_2O	0.51	0.52	0.17	1.00	0.48	0.84	0.83	1.52	1.71	1.91	0.54	0.93	2.20	1.82	2.29
H_2O+	0.52	1.10	0.76	1.36	1.27	0.63	0.05	1.91	1.00	0.14	0.66	0.17	0.38	0.06	0.34
H_2O-	0.34	0.82	0.57	1.01	0.49	0.65	0.03	1.47	0.52	0.08	0.15	0.07	0.22	0.03	0.29
TiO_2	3.17	2.52	3.30	4.42	3.90	2.62	4.12	4.43	4.64	3.27	2.59	2.27	2.74	5.10	2.09
P_2O_5	0.49	0.29	0.22	0.84	0.52	0.50	0.31	1.03	0.89	0.88	0.67	0.55	1.03	0.51	1.10
MnO	0.18	0.17	0.21	0.16	0.19	0.16	0.13	0.18	0.23	0.39	0.09	0.16	0.26	0.24	0.28
Total	100.18	100.46	100.28	100.48	100.04	100.64	100.19	99.77	99.97	100.01	99.78	100.75	100.61	99.87	99.88
Norms															
Quartz	10.4	—	10.4	—	3.9	—	—	1.8	—	—	—	—	2.2	—	—
Orthoclase	2.8	2.8	1.1	6.1	2.8	5.0	5.0	8.9	10.0	11.1	3.3	5.6	12.8	10.6	13.3
Albite	14.7	6.3	10.0	39.3	27.2	21.0	4.7	35.1	41.9	32.0	23.8	19.9	39.3	21.0	34.6
Anorthite	29.8	20.0	27.8	1.4	22.5	13.1	36.7	22.0	11.1	18.4	13.9	6.1	12.5	11.7	15.0
Nepheline	—	3.1	—	1.4	—	1.4	8.8	—	0.3	8.2	1.6	10.8	—	16.5	9.1
Diopside	12.1	32.3	18.0	26.7	16.7	20.6	8.7	2.2	14.0	10.9	25.3	31.0	15.6	21.5	10.4
Hypersthene	18.2	—	18.5	—	8.6	—	—	10.4	—	—	—	—	4.0	—	—
Olivine	—	24.2	—	4.0	—	29.1	25.7	—	1.8	4.9	20.0	17.3	—	1.4	3.8
Magnetite	4.2	4.4	6.5	4.6	7.9	3.0	0.9	5.3	8.4	6.3	4.6	4.9	8.4	6.5	6.7
Ilmenite	6.1	4.7	6.2	8.4	7.4	5.0	7.8	8.4	8.8	6.2	4.9	4.3	5.2	9.7	3.9
Hematite	—	—	—	4.5	—	—	—	—	—	—	—	—	—	—	—
Apatite	1.3	0.7	0.3	2.0	1.3	1.3	0.7	2.4	2.0	2.0	1.7	1.3	2.4	1.3	2.7
Approximate model percentage of anomalous feldspar															
	3	5	7	8	10	10	[a]16	20	20	[a]28	[a]32	[a]34	35	[a]48	50

[a] Percentage quoted from Barth, T. F. W., Mineralogical petrography of Pacific lavas: *Am. Jour. Sci.*, 5th ser., **21,** 511 (1931).

1. Olivine basalt, on ridge on south side of Nanakuli Valley, Waianae volcano, Oahu; S. Iwashita, analyst. Macdonald, G. A., Petrography of the Waianae Range, Oahu, in Stearns, H. T., Supplement to the geology and ground-water resources of the island of Oahu, Hawaii: *Hawaii Div. of Hydrography, Bull.* **5,** 91 (1940).

2. Picritic basalt, northwest base of Namanaokeakua Hill in summit depression of Haleakala volcano; G. Steiger, analyst. Cross, W., Lavas of Hawaii and their relations: *U.S. Geol. Survey, Prof. Paper* **88,** 29 (1915).

3. Olivine basalt, on ridge on south side of Nanakuli Valley, Waianae volcano, Oahu: S. Iwashita, analyst. Macdonald, G. A., *op. cit.*

4. Biotite-bearing andesitic basalt, top of Puu Palailai; S. Iwashita, analyst. *Ibid.*

5. Olivine basalt, just north of saddle on north side of Puu Haleakala, Waianae volcano, Oahu; S. Iwashita, analyst. *Ibid.*

6. Olivine basalt transitional to picritic basalt, at junction of Amalu and Honokowai Streams, West Maui; S. Iwashita, analyst. Stearns, H. T., and Macdonald, G. A., Geology and ground-water resources of the island of Maui, Hawaii: *Hawaii Div. of Hydrography*, Bull. **7,** in press.

7. Picritic basalt, 1750(?) lava flow near Makena, on Haleakala volcano; M. G. Keyes, analyst. Washington, H. S., and Keyes, M. G., Petrology of the Hawaiian Islands; VI. Maui: *Am. Jour. Sci.*, 5th ser., **15,** 214–215 (1928).

8. Basaltic andesite, on ridge on south side of Nanakuli Valley, Waianae volcano, Oahu; S. Iwashita, analyst. Macdonald, G. A., *op. cit.*

9. Biotite-bearing basaltic andesite, on ridge east of Makaiwa Gulch, Waianae volcano, Oahu; S. Iwashita, analyst. *Ibid.*

10. Andesite, at rest house on rim of summit depression of Haleakala volcano; M. G. Keyes, analyst. Washington, H. S., and Keyes, M. G., *op. cit.*, pp. 211–212.

11. Olivine basalt, lava of 1801, Hualalai volcano; Washington, analyst. Washingson, H. S., Petrology of the Hawaiian Islands; II. Hualalai and Mauna Loa: *Am. Jour. Sci.*, 5th ser., **6,** 102 (1923).

12. "Chrysophyric oligoclase basalt," Kaula Gulch, above Ookala, Mauna Kea; Washington, analyst. Washington, H. S., Petrology of the Hawaiian Islands; I. Kohala and Mauna Kea: *Am. Jour. Sci*, 5th ser., **5,** 500 (1923).

13. Andesite, on highway at 380 feet altitude on northwest bank of Manawai Gulch, East Molokai volcano; S. Iwashita, analyst.

14. Basaltic andesite, three miles from rest house, Olinda trail, north slope of Haleakala volcano; M. G. Keyes, analyst. Washington, H. S., and Keyes, M. G.; *op. cit.*, pp. 211–212.

15. Andesite, White Hill, on rim of summit depression of Haleakala volcano; W. F. Hillebrand, analyst. Cross W., *op. cit.*, pp. 31–32.

West Maui volcano, the Palolo boss in the Koolau volcano of Oahu,[15] and certain gabbros from Kahoolawe,[16] there is found a small amount of interstitial orthoclase and sanidine, associated with oligoclase and in one instance with albite. The potash and soda-lime feldspars are often intergrown as antiperthite, which has the appearance of having resulted from the unmixing of two phases formerly in solid solution.

The apparent reciprocal relationship of antiperthite in the gabbros and the abnormal feldspar in the extrusive rocks supports the supposition that the latter may be a solid solution of potash feldspar in soda-lime feldspar, stable at high temperatures but metastable at low temperatures. In the gabbros, slower cooling would permit the unmixing of the solid solution forming antiperthite, or the direct crystallization of the two components as separate but closely associated minerals.

Conclusions

The small positive optic angle of interstitial feldspars with the refractive indices of andesine and oligoclase, found in many Hawaiian lavas, is not the result of an admixture of nepheline or carnegieite, as has previously been suggested. In some phenocrysts the abnormally small optic angle apparently is caused by the superposition of feldspar plates, probably by twinning on the carlsbad or albite laws, the corresponding vibration directions in the superimposed plates being approximately at right angles. In most of the groundmass feldspar, however, there is no evidence that the abnormal properties are the result of such overlapping of differently oriented plates. On the other hand, there is a definite correlation of the amount of abnormal feldspar in the rock with the percentage of normative orthoclase. Therefore, it appears probable that the feldspar with the small optic angle is an andesine or oligoclase containing more or less potash feldspar, in solid solution, stable at high temperatures, but metastable at ordinary temperatures. Following Tomita, it may be termed potash-oligoclase or potash-andesine.[17]

Acknowledgments

The writer wishes to thank Drs. Howel Williams and Cordell Durrell of the University of California at Berkeley and Los Angeles, respectively, Dr. C. S. Ross of the United States Geological Survey, and Dr. Howard Powers of the National Park Service, for their criticisms of this manuscript.

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[15] Stearns, H. T., and Vaksvik, K. N., Geology and ground-water resources of the island of Oahu, Hawaii: *Hawaii Div. of Hydrography, Bull.*, **1**, 21, (1935).

Wentworth, C. K., and Jones, A. E., Intrusive rocks of the leeward slope of the Koolau Range, Oahu: *Jour. Geology*, **48**, 986–988 (1940).

[16] Macdonald, G. A., *op. cit.*, p. 153.

[17] *Op. cit.*, pp. 7–10.

DIFFERENTIAL THERMAL ANALYSIS OF CLAY MINERALS AND OTHER HYDROUS MATERIALS. PART 2.

Ralph E. Grim and Richards A. Rowland†

(*Continued from page 761*)

Materials that have been called beidellite

The samples represented by differential thermal curves in Fig. 8 have been classified as beidellite chiefly on the basis of their optical properties. Sample 8A has a curve like that of kaolinite, or a halloysite, because of the endothermic peak between 500°C. and 600°C., the sharp exothermic peak, and the absence of a third endothermic peak. The initial endothermic peak suggests hydrated halloysite rather than kaolinite, and the hump at 400°C. reflects the presence of a ferric iron hydrate. The trace of a peak between 600°C. and 700°C. indicates the presence of a small amount of montmorillonite. *X*-ray diffraction analysis checks these identifications, showing the dominant constituent to be a two-layer type clay mineral. The low silica-alumina molecular ratio shown by the chemical analysis (Table 4) is also in accord with this interpretation, but the K_2O content suggests that the sample also contains illite.

Under the microscope this sample (8A) appears to be homogeneous except for pigmentary hydrated ferric iron oxide, and the optical properties can be closely approximated ($\gamma=1.580$, $\gamma-\alpha=.025$). It is clear that a study of the optical properties alone might lead easily to a misinterpretation of the composition of the sample. A correlation of optical, chemical, *x*-ray, and thermal data for this and other samples shows clearly that mixtures of clay minerals and hydroxides can be so closely intergrown that the obtainable optical data for the mixtures suggest homogeneity and a composition other than the actual one. This does not reduce the value of optical data in clay mineral work but it does mean that such data must be used with caution, particularly when the determinations are incomplete and approximate.

The differential thermal curves of samples 8B and 8C are closely alike, and they indicate the presence of a small amount of montmorillonite and a dominant amount of illite, kaolinite, or a halloysite. Because of the smallness of the third endothermic peak and the large size of the initial peak, hydrated halloysite is suggested as a prominent constituent. The *x*-ray diffraction patterns of these samples are very poor and indicate only that they contain a small amount of an expanding-lattice type clay mineral. The K_2O content shown by the chemical analyses (Table 4) suggests that illite is an important constituent. It seems clear that these samples are mixtures of a halloysite and illite with a very small amount of montmorillonite. Only a mean index of refraction could be determined for the samples, and optical study alone would not disclose the true composition of the materials.

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† Petrographer and Assistant Petrographer, respectively, Illinois State Geological Survey, Urbana, Illinois.

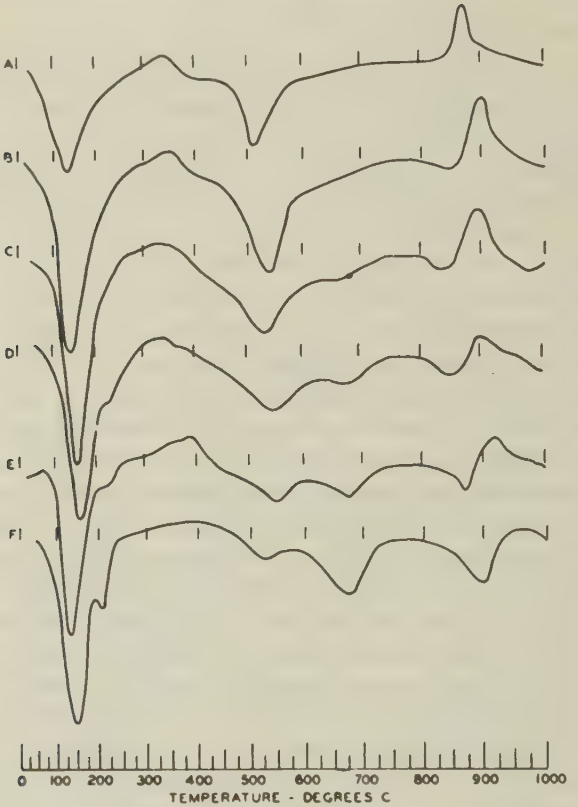

FIG. 8. Materials that have been called beidellite. Scale A.

A. Namiquipa, Chihuahua, Mexico, U. S. Nat. Mus. No. R7595.
B. Fairview, Utah.
C. Twin Falls, Idaho.
D. Beidell, Colorado, U. S. Nat. Mus. No. 93239.
E. Wagon Wheel Gap, Colorado, U. S. Nat. Mus. No. 94963.
F. Nashville, Arkansas.

Sample 8D, crude material from the type beidellite locality, gave a curve similar to 8B and 8C and it is concluded that the material is primarily a mixture of a halloysite, illite and montmorillonite. The x-ray diffraction pattern of this material was very poor and indicated only the presence of some montmorillonite. A differential thermal curve was also obtained for a sample in which an attempt was made to hand-pick homogeneous material. The curve for the hand-picked material was the same as the curve for the crude sample except that the size of the peak between 600° C. and 700° C. increased. An *x*-ray analysis of the hand-picked material showed more pronounced montmorillonite diffractions than did the crude sample. It seems clear that the material from Beidell, Colorado, even if purified by hand-picking, is a mixture and not a single species. Again, on the basis of optical properties alone, one might conclude that the hand-picked material was homogeneous.

The curve for sample 8E is similar to the curve for sample 8D except that the endothermic peak at 600–700°C. is more pronounced, indicating a greater proportion of montmorillonite. The curve for 8F is also similar except that the montmorillonite peak is still larger, indicating an even larger amount of this mineral. The diffraction pattern for sample 8E showed the montmorillonite lines more distinctly than in previous samples of this series, and the montmorillonite lines in the pattern for sample 8F were even more pronounced. The *x*-ray evidence is therefore in accord

TABLE 4. CHEMICAL ANALYSES OF MATERIALS THAT HAVE BEEN CALLED BEIDELLITE

	8A	8B	8C	8D	8E	8F
SiO_2	43.76	51.65	55.48	47.28	52.80	45.52
Al_2O_3	27.88	26.40	20.83	20.27	25.66	27.52
Fe_2O_3	6.42	5.53	7.76	8.68	6.47	2.80
FeO		.29	.15		.31	
MgO	1.23	2.48	3.23	.70	1.76	3.00
CaO	.90	1.36	1.45	2.75	2.11	.52
Na_2O	.30	.15	.40	.97	.06	
K_2O	1.18	1.88	2.19	tr	1.09	
TiO_2	.30	.49	.88		.39	
Ign. loss		10.21	8.18		8.98	
Total		100.44	100.55		99.63	
H_2O+	7.67	10.08	7.47	19.72	8.70	19.60
H_2O-	10.59	5.99	7.15		7.26	
SiO_2/R_2O_3	2.33	2.90	3.67	3.11	3.00	2.55
SiO_2/Al_2O_3	2.66	3.32	4.53	3.96	3.49	2.81

Analyses 8B, 8C and 8E were made under the supervision of O. W. Rees, Ill. State Geol. Survey.

8A Namiquipa, Chihuahua, Mexico. Analysis from W. F. Foshag, U. S. Nat. Museum.
8B Fairview, Utah.
8C Twin Falls, Idaho.
8D Beidell, Colorado. *Jour. Am. Cer. Soc.*, **9**, 94 (1926).
8E Wagon Wheel Gap, Colorado.
8F Nashville, Arkansas. *Jour. Am. Cer. Soc.* **9**, 94 (1926).

with the conclusions that samples 8E and 8F contain a relatively larger amount of montmorillonite than the other members of this series. Sample 8F appears under the microscope to be a mixture, whereas sample 8E has the appearance of a single species. The optical properties of 8E can be accurately determined ($\gamma=1.560$, $\gamma-\alpha=.030$ $(-)$) and on these data alone one might easily conclude that the material was a single species and not a mixture.

The curves of all of the so-called beidellite samples show an endothermic hump or a suggestion of one at about 400°C. to 500°C. This is in the temperature range of the endothermic reaction of hydrated ferric iron oxides, and this is believed to be the proper interpretation since optical study reveals the presence of some such material in these samples. However, the study of so-called "nontronite" and "chloropal" (samples 12A and 13D) suggests that some expanding-lattice type clay minerals, probably those containing ferric iron instead of aluminum, may show an endothermic reaction between 400°C. and 500°C. It is possible, therefore, that the hump on the curves between 400°C. and 500°C. may reflect the presence of a trace of this type expanding-lattice clay mineral as well as ferric iron hydrate.

The data herein presented do not necessarily mean that beidellite is not a valid species. They do show that much of the material classed as beidellite, including that from the type locality, is actually a mixture of clay minerals and hydrated ferric iron oxide. Norton (22) presented curves for beidellite showing endothermic peaks between 500°C. and 600°C. and at 690°C. but failed to suggest that the curves indicated mixtures. Orcel and Caillere (25) and Jourdain (15) also presented curves for beidellite showing endothermic peaks between 550°C. and 600°C. which they interpreted as due to kaolinite. It seems likely, on the basis of the present data, that the peak between 550°C. and 600°C. in many samples is due to illite whereas in others it reflects the presence of kaolinite or a halloysite.

Prepared mixtures of montmorillonite and illite

Orcel (24) and Norton (22) have published curves of prepared mixtures of kaolinite and montmorillonite, but synthetic mixtures of other clay minerals have not been studied previously.

Differential thermal curves for illites and montmorillonite show endothermic peaks at 100–250°C. and about 900°C., and an exothermic peak following the 900°C. endothermic peak. The substitution of one of these clay minerals for another in a mixture is not reflected in any of the thermal reactions at these temperatures. Thermal curves for montmorillonite show an endothermic peak at about 700°C. and none between 500°C.

and 600°C., whereas illite curves show an endothermic peak between 500°C. and 600°C., and none at about 700°C. As shown in Fig. 9 the substitution of montmorillonite for illite in a mixture is clearly reflected quantitatively by the second endothermic peak.

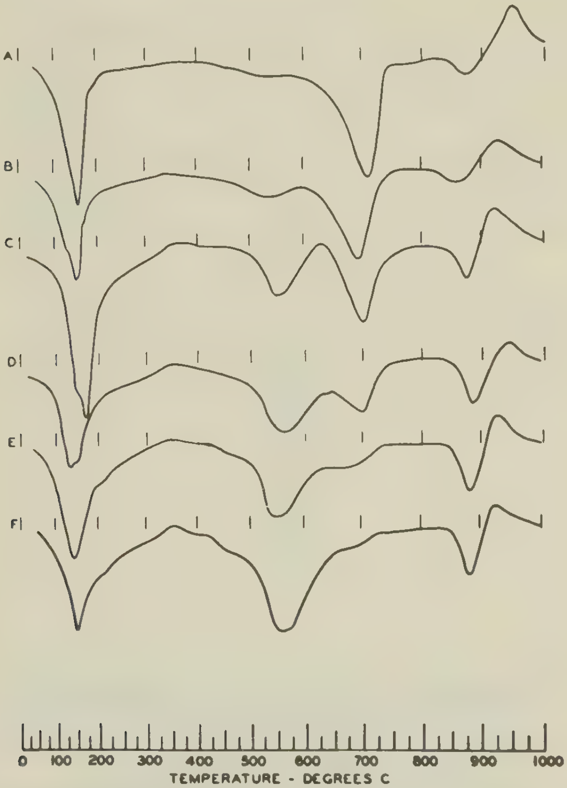

Fig. 9. Prepared mixtures of montmorillonite (5D) and illite (4D). Scale A.

A. 90% montmorillonite, 10% illite.
B. 75% montmorillonite, 25% illite.
C. 50% montmorillonite, 50% illite.
D. 25% montmorillonite, 75% illite.
E. 10% montmorillonite, 90% illite.
F. 5% montmorillonite, 95% illite.

Prepared mixtures of illite and kaolinite.

Illites show endothermic reactions at 100–250°C. and at about 900°C. whereas kaolinite does not show a thermal reaction at either temperature. The substitution of illite for kaolinite in mixtures is indicated quantitatively by peaks representing these reactions in the curves as shown in Fig. 10. The final exothermic reactions are distinctive for each of these clay minerals so that the substitution of illite for kaolinite is indicated also by the portion of the curve showing these reactions. Both kaolinite and illites show endothermic reactions between 500°C. and 600°C. However, the mixing of kaolinite and illite is reflected to some extent in the peak representing this reaction because of the much greater magnitude of the reaction for kaolinite than for illites.

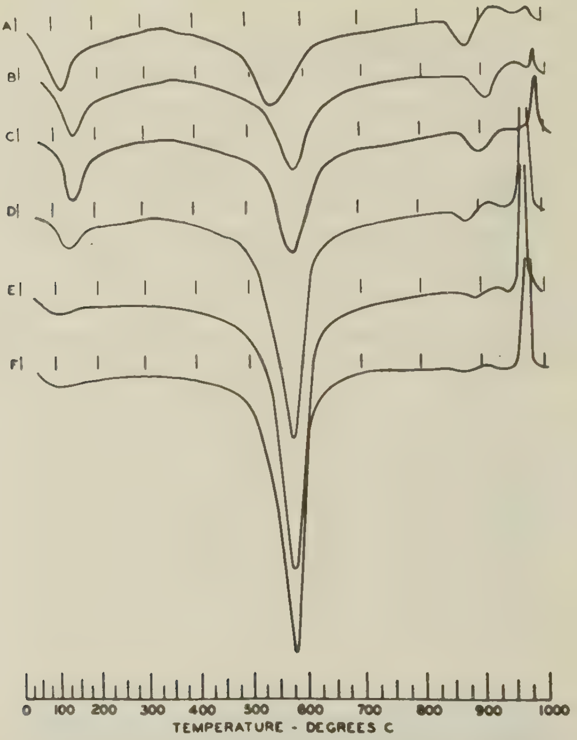

Fig. 10. Prepared mixtures of illite (4D) and kaolinite (3C). Scale B.
A. 95% illite, 5% kaolinite.
B. 90% illite, 10% kaolinite.
C. 75% illite, 25% kaolinite.
D. 50% illite, 50% kaolinite.
E. 25% illite, 75% kaolinite.
F. 10% illite, 90% kaolinite.

Miscellaneous minerals

In order to obtain the necessary background for the interpretation of the differential thermal analyses of clays, differential thermal analyses were made of a large number of specimens of hydrous material. Many of these samples were obtained from the United States National Museum, and the authors are indebted to Drs. W. F. Foshag and E. P. Henderson for their kindness in supplying them. Differential thermal curves of these samples are presented in Figs. 11 to 14. In many samples the curves suggest that the species is not valid, but other characteristics of most of the samples require study before this point can be settled definitely.

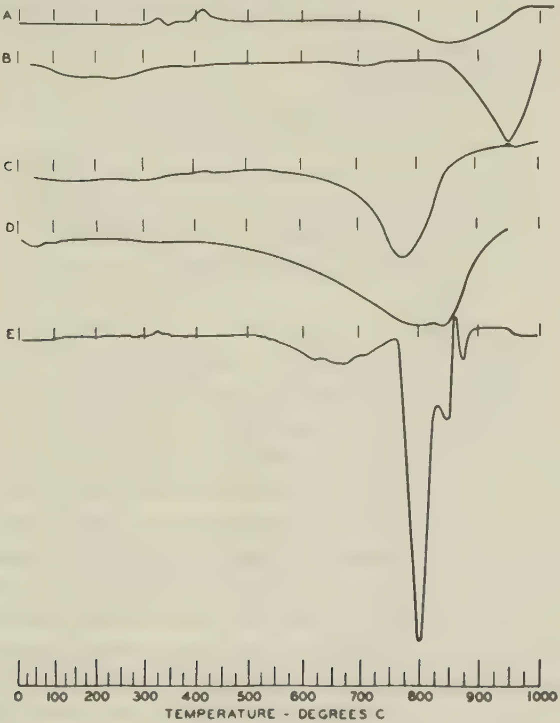

FIG. 11. Miscellaneous minerals. Scale A.
A. Muscovite, University of Illinois collections.
B. Talc, Vermont.
C. Pyrophyllite, North Carolina.
D. Pyrophyllite, Oreana, Nevada.
E. Chlorite, Chester, Massachusetts.

The curve for muscovite presented in Fig. 11A shows a broad endothermic reaction between 750°C. and 950°C., and small peaks from 300°C. to 400°C. which may or may not be significant. This curve does not agree with those published for muscovite by Orcel (24) and Norton (22). It is quite possible that all the muscovite curves so far published are not significant, because the coarse flakes permit only a small amount to be packed loosely in the specimen holder. Consequently inherent limitations of the differential thermal method are magnified and reproducible results are difficult to obtain.

The curve for talc (sample 11B) is in agreement with the curves for this mineral published by Orcel (24) and Norton (22).

The curve for the pyrophyllite sample from North Carolina (sample 11C) is believed to be significant for the mineral. The other sample of pyrophyllite (11D) is not pure, and its curve is less significant. The curve for sample 11C checks Orcel's (24) findings for pyrophyllite, but not Norton's (22).

Orcel (23) has published a large variety of curves for the chlorites but none of them is like that shown for chlorite sample 11E. A study of many chlorites, combining *x*-ray, thermal, and chemical analytical data, is needed before this group of minerals will be well understood.

Sample 12A, "nontronite" from San Luis, Potosi, Mexico, is shown by microscopic study to be composed of about thirty per cent quartz, ten per cent ferric iron hydrate, and the remainder a clay mineral that has the optical properties of nontronite. An *x*-ray diffraction analysis of the sample showed lines characteristic of clay minerals with an expanding lattice, in addition to lines for quartz and ferric iron hydrate. The differential thermal curve is not exactly like the curves of known materials, and is particularly characterized by an endothermic peak between 400°C. and 500°C. Since the relative amount of ferric iron hydrate in the sample is too small to cause this thermal effect, and quartz does not exhibit a thermal reaction at this temperature, it seems likely that it results from the clay mineral with the expanding lattice. These data suggest that iron-rich clay minerals of the expanding lattice type exhibit a second endothermic reaction about 200°C. lower than the aluminous variety. Some ferric iron hydrates show an endothermic reaction between 400°C. and 500°C., and it may be difficult to determine if a peak in this temperature interval has resulted from a clay mineral or a ferric iron hydrate.

The differential thermal curve of the "woody nontronite" (Fig. 12B) indicates a mixture of illite, montmorillonite, and a ferric iron hydrate or an iron-rich expanding-lattice type clay mineral. The optical characteristics of the sample ($\gamma = 1.535$, $\gamma - \alpha = .030$) can be measured accurately, and again on the basis of optical data alone the sample might easily be designated as a single homogeneous mineral.

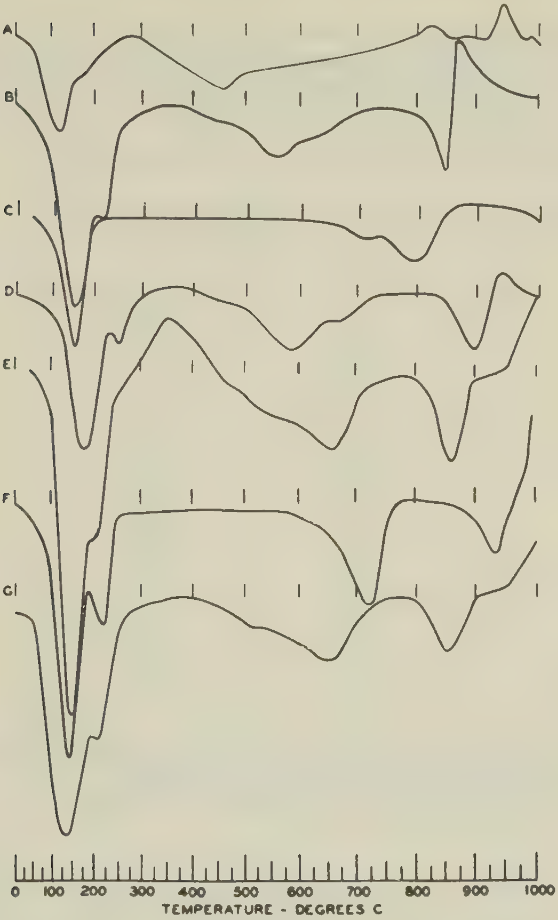

FIG. 12. Miscellaneous materials. Scale A.

A. "Nontronite," San Luis, Potosi, Mexico, U. S. Nat. Mus. No. R6685.
B. "Woody nontronite," Howard County, Arkansas.
C. White Hector clay, Hector, California.
D. Bravaisite, Noyant Allier, France, U. S. Nat. Mus. No. 4918.
E. "Smectite," Cilly, Austria, U. S. Nat. Mus. No. 13098.
F. "Leverrierite," April Fool Hill, Manhattan, Nevada, U. S. Nat. Mus. No. 3819.
G. "Leverrierite," Salida, Colorado, U. S. Nat. Mus. No. 94962.

The sample of white magnesium clay from near Hector, California, described by Foshag and Woodford (7), gives a unique curve (Fig. 12C). The curve is unlike the montmorillonite curves, suggesting that the material should not be classed in this group of clay minerals. Under the microscope, the sample seems to be a single species.

Bravaisite from the type locality yields a differential thermal curve (Fig. 12D) like that of the illites with an additional endothermic peak close to 700°C. suggesting the presence of a small amount of montmorillonite. The chemical composition of bravaisite (Table 5) and its optical properties ($\gamma = 1.552$, $\gamma - \alpha = .025$ (−)) are also similar to the illites.

TABLE 5. CHEMICAL ANALYSES OF ILLITES AND BRAVAISITE.

	4C	4D	12D
SiO_2	52.23	51.22	54.64
Al_2O_3	25.85	25.91	26.29
Fe_2O_3	4.04	4.59	1.51
FeO		1.70	0.38
MgO	2.69	2.84	3.03
CaO	0.60	0.16	1.40
Na_2O	0.33	0.17	0.12
K_2O	6.56	6.09	5.94
TiO_2	0.37	0.53	0.45
Ign. loss	7.88	7.49	6.68
Total	100.55	100.70	100.44
H_2O+	7.88	7.14	6.61
H_2O-	1.13	1.45	4.28
SiO_2/R_2O_3	3.13	3.02	3.41
SiO_2/Al_2O_3	3.43	3.36	3.53

Analyses made under the supervision of O. W. Rees, Ill. State Geol. Survey.
4C Illite, purified from shale, Alexander County, Illinois.
4D Illite, purified from underclay, Vermilion County, Illinois.
12D Bravaisite, Noyant Allier, France.

The differential thermal curve for the smectite sample (Fig. 12E) is like that of montmorillonite. The presence of a small amount of illite is suggested by the endothermic hump between 500°C. and 600°C., and the exothermic reaction between 250°C. and 450°C. indicates the presence of organic material. This is in agreement with Kerr's (17) conclusion that smectite is not a valid species because of its similarity to montmorillonite.

The curves for two samples labeled leverrierite (Figs. 12F and 12G) are like those of montmorillonite. The second endothermic peak of sample 12F occurs at a temperature slightly above that usually found for montmorillonite, but probably not too high for that identification. Sample 12F has the optical properties of montmorillonite, whereas sample 12G appears to be only faintly anisotropic with a mean index of refraction of about 1.470. On the basis of optical data the latter sample would be classed as allophane, illustrating again the caution necessary in identifying clay minerals from a single criterion. The very low apparent birefringence of sample 12G is probably due to a random orientation of the clay mineral particles mixed with some isotropic material. *X*-ray diffraction

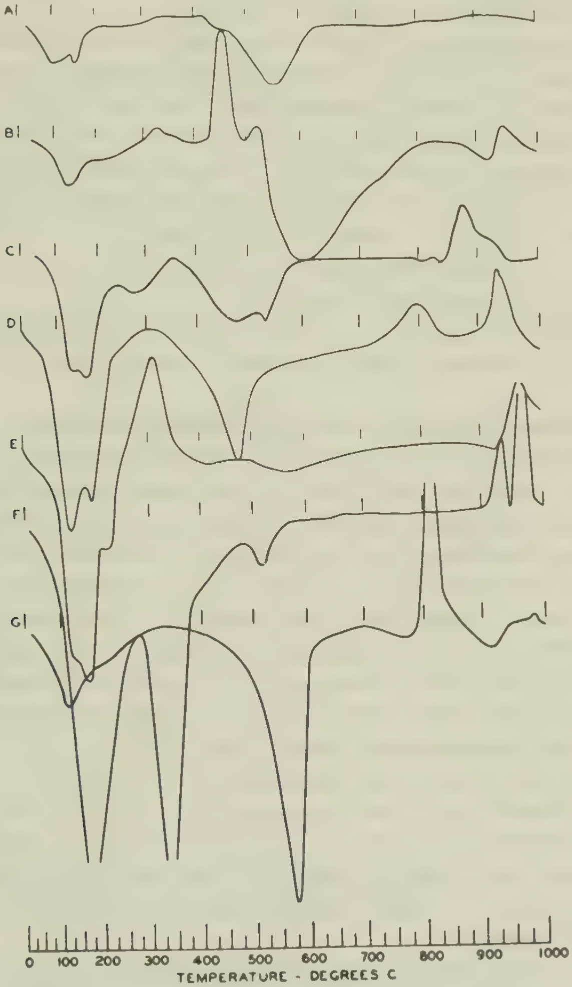

FIG. 13. Miscellaneous materials. Scale A.

A. Rectorite, Garland County, Arkansas, U. S. Nat. Mus. No. 80607.
B. Celadonite, Verona, Italy. U. S. Nat. Mus. No. 93080.
C. Attapulgite, Quincy, Florida.
D. "Chloropal," Hungary, U. S. Nat. Mus. No. 80644.
E. Volkonskoite, near Sverdlosk, U. S. S. R.
F. "Allophane," Bedford, Indiana, U. S. Nat. Mus. No. 95335.
G. "Allophane," Iyo, Japan, U. S. Nat. Mus. No. 93052.

analyses of both samples gave good patterns characteristic of the expanding-lattice type clay minerals. Samples of leverrierite studied by Ross and Kerr (29) proved to be kaolinite, and de Lapparent (19) has described leverrierite as an intergrowth of kaolinite and mica. Clearly the term does not designate a valid mineral species.

The differential thermal curve for the sample of rectorite (Fig. 13A) is unique. Under the microscope the sample has the appearance of a halloysite with some additional hydrated ferric iron oxide which may be responsible for the slight endothermic hump in the curve at about 450°C.

The differential curve for the celadonite sample (Fig. 13B) is unique except that the three endothermic peaks are somewhat similar to the endothermic peaks of the illites. The optical properties of the sample are like those of glauconite. The sharp exothermic reaction at about 450°C. probably results from organic material.

Attapulgite gives a curve (Fig. 13C) unlike that of the other minerals studied and this supports the conclusion (1) that the material is a distinct species.

The differential thermal curve for the sample of "chloropal" (Fig. 13D) is much the same as the curve for the "nontronite" from San Luis, Potosi, Mexico. An *x*-ray analysis of the "chloropal" sample indicated that the prominent constituent has an expanding lattice. Therefore, this sample provides further evidence that certain clay minerals with an expanding lattice may show an endothermic peak between 400°C. and 500°C. The samples of expanding lattice material with the endothermic peak between 400°C. and 500°C. show two exothermic peaks between 800°C. and 1000°C., and they do not show a third endothermic peak. In all of these characteristics the curves are unlike those of the expanding-lattice material with an endothermic peak at 600° to 700°C.

The curve for the sample of volkonskoite (13E) is distinctive because it shows no endothermic reaction above 250°C., i.e., no thermal reaction corresponding to a loss of lattice water. Under the microscope the volkonskoite appears to be an amorphous substance with a pigmentary material distributed through it. The material is listed by Dana (5) as a chrome-bearing clay.

The sample labeled "allophane" from Bedford, Indiana, (13F) gave a curve suggesting a mixture of kaolinite or a halloysite because of the 525°C. endothermic and 950°C. exothermic peaks, gibbsite because of the 350°C. endothermic peak, and amorphous material. The 925°C. exothermic peak is difficult to explain but it is probably due to the amorphous material. This and other samples suggest that amorphous hydrous aluminum silicate materials show only a single endothermic reaction

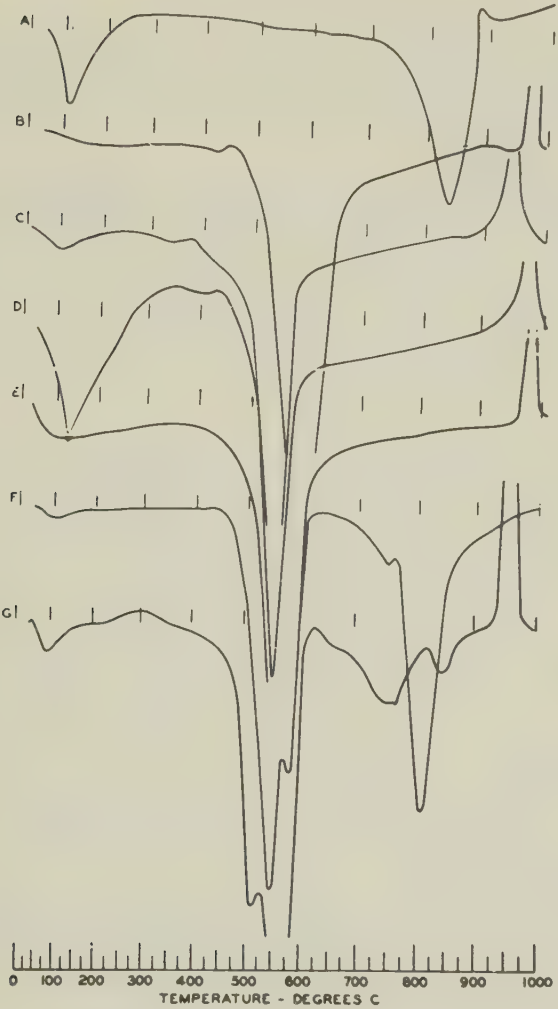

FIG. 14. Miscellaneous materials. Scale A.

A. Racewinite, Bingham, Utah, U. S. Nat. Mus. No. R4759.
B. Dillnite, Schemnitz, Hungary, U. S. Nat. Mus. No. R4795.
C. Severite, Elko, Nevada, U. S. Nat. Mus. No. 13511.
D. Miloschite, Rudniak, Serbia, U. S. Nat. Mus. No. 48649.
E. Collyrite, Fichtelgebirge, Bavaria, U. S. Nat. Mus. No. R4793.
F. Cimolite, Sverdlosk, U. S. S. R., U. S. Nat. Mus. No. R4765.
G. Newtonite, Newton, Pennsylvania, U. S. Nat. Mus. No. R4760.

which occurs below about 250°C. Optical study of the sample indicates a mixture containing a considerable amount of kaolinite or a halloysite.

The sample of "allophane" from Iyo, Japan, gives a differential thermal curve (Fig. 13G) like that of a halloysite except that the exothermic reaction takes place at a lower temperature. The sample has the optical characteristics of a halloysite.

The sample of racewinite (14A) from the type locality appears under the microscope to be a mixture of amorphous material and carbonate, and this is the composition suggested by the curve. The endothermic peak between 750°C. and 875°C. is in the range in which carbonates show endothermic reactions,* and the endothermic reaction below 250°C. is in the range of the thermal reaction of amorphous material.

The sample of dillnite yielded a differential thermal curve (Fig. 14B) exactly like kaolinite, and the optical characteristics of the sample are identical with those of kaolinite.

The curve for the sample of severite (Fig. 14C) is also similar to the curve for kaolinite, except that the initial low temperature endothermic peak suggests the presence also of a halloysite. The optical characteristics of this sample are like those of a halloysite or kaolinite.

The miloschite sample gave a differential thermal curve (Fig. 14D) indicating the presence of kaolinite and/or a halloysite. The initial endothermic peak is broader than that for hydrated halloysite and probably indicates the presence of some amorphous material. Optical study of the sample shows material with the optical properties of a halloysite pigmented with amorphous material. Miloschite is listed by Dana (5) as a chromiferous clay.

The curve for the sample of collyrite (Fig. 14E) is also like that for kaolinite and/or a halloysite. The optical characteristics of the sample are like those of a halloysite.

The differential thermal curve for the sample of cimolite (Fig. 14F) is unlike the other curves. An *x*-ray diffraction analysis shows the presence of alunite, but further study is required to determine if the curve is characteristic of alunite.

The curve for the sample of newtonite (Fig. 14G) suggests the presence of kaolinite and/or a halloysite because of the endothermic peak between 500°C. and 600°C. and the sharp exothermic peak at about 950°C. The endothermic peaks between 700°C. and 900°C. indicate the presence of additional material which cannot be identified. Under the microscope the sample has the optical characteristics of kaolinite. Ross and Kerr (29) have shown that samples of newtonite studied by them were actually kaolinite.

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* Unpublished work by R. A. Rowland and F. L. Cuthbert: Illinois State Geological Survey, Urbana, Ill.

Summary and Discussion

Kaolinite and halloysite type clay minerals are characterized by a sharp endothermic reaction between 500°C. and 600°C., and by a very abrupt exothermic reaction at about 950°C. Hydrated halloysite shows an additional sharp endothermic reaction between about 100°C. and 200°C.

Illites give endothermic peaks between 100°C. and 250°C., 500°C. and 650°C., and at about 900°C. and an exothermic peak immediately following the third endothermic peak. Montmorillonite gives a curve similar to that for illites except that the initial endothermic curve is larger and the second endothermic reaction takes place at about 100°C. higher temperature (600° to 700°C.). For both of them the exothermic reaction shifts to a slightly lower temperature as the iron content increases.

The third endothermic reaction at about 900°C. has not been found in two-layer-lattice clay minerals, and seems to be characteristic of the three-layer types, i.e., illites and montmorillonite. Illites and montmorillonite are largely dehydrated in the temperature range of the second endothermic peak, but their lattice structure is not destroyed until a higher temperature is reached, and this is followed at once by the formation of spinel. It is believed that the third endothermic peak corresponds to the final destruction of the lattice and the exothermic reaction to the formation of spinel.

In the case of the three-layer clay minerals an endothermic peak between 500°C. and 600°C. seems to be characteristic of the non-swelling type (illites) and one between 600°C. to 700°C. appears to be characteristic of the swelling type (montmorillonite). No swelling material has been found to have an endothermic peak between 500°C. and 600°C. and only one example of a non-swelling material (metabentonite, sample 6B) has been found to have an endothermic reaction between 600°C. and 700°C. However, the sample of "nontronite" from Mexico (12A) and the sample of "chloropal" (13D) which gives a thermal curve similar to that of "nontronite," suggest that iron-rich expanding-lattice-type clay minerals may show their second endothermic peak at a lower temperature (400°C. to 500°C) than that of the illites, and in the same temperature interval in which the endothermic reaction in some ferric iron hydrates takes place.

Kaolinite and halloysites require considerably more energy for dehydration than illites or montmorillonite. The temperature difference indicated for this reaction in kaolinite and halloysites is about ten times that of the other clay minerals. Because of this large difference, apparatus designed for kaolinite may not detect the thermal reactions of the other clay minerals unless special provisions are made to vary the vertical exaggeration of the record of the thermal reactions by varying the resistance in the galvanometer circuit of the difference thermocouple.

Pore water in the samples does not show in the thermal curves above 100°C. Montmorillonite, illites, and hydrated halloysite all show initial endothermic reactions below about 200°C. It is suggested from information regarding the structure of montmorillonite that this water is held on the basal planes of the unit cells and that it may have distinctive properties. It corresponds to "planar water" as defined by Kelley (16) and his colleagues. The thermal data suggest that certain clay minerals, e.g., illites, can have some of this type of water without also having an expanding lattice.

The thermal evidence indicates that many bentonites and other clays thought to be composed of a single clay mineral are actually mixtures of clay minerals probably closely intergrown. Many of the bentonites are mixtures of illite and montmorillonite; others are mixtures of kaolinite and/or a halloysite and montmorillonite. In some of these clays montmorillonite does not seem to be the dominant constituent. *X*-ray and optical data are in accord with these conclusions.

A series of samples that have been classed as beidellite, including material from the type locality at Beidell, Colorado, gave differential thermal curves indicating that they are not composed of a single species, but are mixtures of clay minerals. *X*-ray diffraction data are not opposed to this conclusion. Some of these mixtures yield optical data that suggest homogeneous material and so might easily lead to erroneous identifications. The sample from the Princess Mine, Namiquipa, Chihuahua, Mexico, is a particularly good example because *x*-ray and thermal data show definitely that it is a mixture primarily of kaolinite and/or a halloysite and a ferric iron hydrate, whereas its apparent moderately high birefringence and indices of refraction would not suggest this identification. This does not reduce the value of optical studies in clay mineral investigations, but it does emphasize the fact that trustworthy clay mineral identifications usually require the study of more than one set of properties. Undoubtedly the literature is full of clay mineral identifications that are inaccurate because they are based either on optical, *x*-ray, thermal, or chemical data, but not on a combination of several of these data.

Differential thermal analyses are presented for a series of additional miscellaneous hydrous minerals that were investigated primarily to provide a background for the clay mineral study. These samples were obtained mainly from the collection of the U. S. National Museum. Some of the salient conclusions from this work are as follows:

Attapulgite and the white magnesium clay mineral from Hector, California, each show distinctive differential thermal curves unlike that of montmorillonite or any other clay mineral. Bravaisite from the type locality has the same thermal characteristics, optical properties, and chemical composition as the illites. A sample of celadonite also yielded a differential curve similar to that of the illites. A sample of smectite had the thermal properties of montmorillonite, which is further evidence for Kerr's (17) conclusion that smectite is montmorillonite.

Two samples of leverrierite proved to be montmorillonite. Other samples studied before by Ross and Kerr (29) and by de Lapparent (19) have another clay mineral composition so that the term can have no standing as a specific mineral name.

A sample of volkonskoite appeared from its curve to be a mixture of amorphous material and a pigmentary material, perhaps chromic oxide. Similarly a sample of racewinite from the type locality seems to be a mixture of amorphous material and a carbonate.

One sample labeled allophane gave a differential thermal curve suggesting a mixture of gibbsite, amorphous material, and a halloysite. Another sample of allophane from another locality proved to be chiefly a halloysite.

Samples labeled respectively dillnite, severite, miloschite, and collyrite gave differential thermal curves exactly like that of kaolinite and/or a halloysite. Optical data confirm this classification of the material. A sample of newtonite also gave a differential thermal curve of the same type, but had in addition several small peaks indicating unidentified constituents.

Samples labeled cimolite and rectonite yielded differential thermal curves different from those of any other materials studied.

REFERENCES

1. BRADLEY, W. F., The structural scheme of attapulgite: *Am. Mineral.*, **25**, 405–410 (1940).
2. BRAGG, W. L., Atomic Structure of Minerals. Cornell Univ. Press (1937).
3. BÜSSEM, W., AND KÖBERICH, F., The hydration of brucite: *Zeits. phys. chem.*, Abt. B, **17**, 310–326 (1932).
4. LE CHATELIER, H., The action of heat on clays: *Bull. soc. franc. min.*, **10**, 204–211 (1887).
5. DANA, J. D., System of Mineralogy. John Wiley & Sons, New York (1914).
6. DEFLANDRE, M., Crystal structure of diaspore: *Bull. soc. franc. min.*, **55**, 140–165 (1932).
7. FOSHAG, W. F., AND WOODFORD, A. O., Bentonitic magnesium clay mineral from California: *Am. Mineral.*, **21**, 238–244 (1936).
8. GRIM, R. E., Modern concepts of clay materials. Presented at 50th Anniversary Univ. of Chicago founding, Chicago, Sept. 1941. *Jour. Geology*, **50**, (3), 225–275 (1942); *Illinois Geol. Survey Rept. Inv.* **80** (1942).
9. GRIM, R. E., AND BRADLEY, W. F., Investigation of the effect of heat on the clay minerals illite and montmorillonite: *Jour. Am. Cer. Soc.*, **23**, 242–248 (1940).

10. Grim, R. E., Bray, R. H., and Bradley, W. F., The mica in argillaceous sediments: *Am. Mineral.*, **22**, 813–829 (1937).
11. Hendricks, S. B., On the structure of the clay minerals: dickite, halloysite, and hydrated halloysite: *Am. Mineral.*, **23**, 275–301. (1938).
12. Hendricks, S. B., and Jefferson, M. E., Structures of kaolin and talc-pyrophyllite hydrates and their bearing on water sorption of the clays: *Am. Mineral.*, **23**, 863–875 (1938).
13. Hendricks, S. B., Nelson, R. A., and Alexander, L. T., Hydration mechanism of the clay mineral montmorillonite saturated with various cations: *Jour. Am. Chem. Soc.*, **62**, 1457–1464 (1940).
14. Insley, H., and Ewell, R. H., Thermal behavior of kaolin minerals: *Jour. of Research, U. S. Bur. of Standards*, **14**, 615–627 (1935).
15. Jourdain, A., Studies of the constituents of refractory clays by means of thermal analysis: *Ceramique*, **40**, 135–141 (1937).
16. Kelley, W. P., Jenny, H., and Brown, S. M., Hydration of minerals and soil colloids in relation to crystal structure: *Soil Sci.*, **41**, 259–274 (1936).
17. Kerr, P. F., Montmorillonite or smectite as constituents of fuller's earth and bentonite: *Am. Mineral.*, **17**, 192–197 (1932).
18. Kumanin, K. G., and Kalnen, N. S., The effect of some experimental factors on the geometrical elements of heating curves: *Jour. Phys. Chem.* (U.S.S.R), **7**, 405–417 (1936).
19. de Lapparent, J., Constitution and origin of leverrierite: *Comptes Rendus*, **198**, 667–671 (1934).
20. Maegdefrau, E., and Hofmann, U., The mica-like clay minerals: *Zeits. Krist.*, **98**, 31–59 (1937).
21. Mehmel, M., On the structure of halloysite and metahalloysite: *Zeits. Krist.*, **90**, 35–43 (1935).
22. Norton, F. H., Critical study of the differential thermal method for the identification of the clay minerals: *Jour. Am. Cer. Soc.*, **22**, 54–63 (1939).
23. Orcel, J., Thermal analyses of chlorites: *Bull. soc. franc. min.*, **50**, 278–322 (1927).
24. Orcel, J., Differential thermal analysis in the determination of the constituents of clays, laterites, and bauxites: *Congr. Int. des Mines, Met. Geol. Applig.*, **VII** Session, 359–373, Paris (1935).
25. Orcel, J., and Cailliere, S., Differential thermal analysis of montmorillonite (bentonite): *Comptes Rendus*, **147**, 774–776 (1933).
26. Posnjak, E., and Merwin, H. E., Hydrated ferric iron oxides: *Am. Jour. Sci.*, 4th Ser., **47**, 311–348 (1919).
27. Rees, O. W., Reed, F. H., and Land, G. W., A study of the equilibriation method of determining moisture in coal for classification by rank: *Rept. Inv.* **58**, *Illinois Geol. Survey* (1939).
28. Rogers, A. F., The crystallography of hydromagnesite: *Am. Jour. Sci.*, **206**, 37–47 (1923).
29. Ross, C. S., and Kerr, P. F., The kaolin minerals: *U. S. Geol. Survey, Prof. Paper* **165-E**, 25 pp. (1931).
30. Schwiersch, H., Thermal decomposition of natural hydroxides of aluminum and trivalent iron: *Chem. d. Erde*, **8**, 252–315 (1933).
31. Wohlen, R., Thermal analyses of clays, bauxites and some allied materials: *Sprechsaal*, **46**, 719–721, 733–735, 749–751, 767–769, 781–783 (1913).

THE GNOMONIC PROJECTION IN THE HEXAGONAL SYSTEM

Lewis S. Ramsdell,
University of Michigan, Ann Arbor, Michigan.

Abstract

The implications of the alternative settings G_1 and G_2 used in the gnomonic projections of hexagonal crystals are made clear by constructing the unit cells from which the two projections are derived. This process reveals that G_1 is based on a simple hexagonal unit cell, in conventional orientation, and with the usual axial ratio. G_2 is based on a triple cell, not in the conventional orientation, and with a different axial ratio. This situation, especially with reference to the axial ratios, has not been generally recognized in the past. The G_2 setting has been commonly used for rhombohedral crystals, but the triple cell on which it is based has no direct relationship to the actual rhombohedral cell. It is concluded that there is no reason for the continued use of the G_2 setting, either for hexagonal or rhombohedral crystals.

There has arisen much confusion in the use of two-circle goniometric measurements and gnomonic projections of hexagonal crystals, largely because of the alternative settings, which were designated by Goldschmidt as G_1 and G_2, respectively. This confusion has been especially noticeable in the determination of the axial ratio for the G_1 setting, and in the derivation of the Bravais indices from the G_2 symbols.[1] It is the purpose of this paper to re-examine the gnomonic projection in these two settings, and to see if any clarification is possible.

In the usual procedure, the gnomonic projection is constructed from measurements made on an actual crystal. It can equally well be constructed from the measurements of a unit cell. For our present purpose it is necessary to reverse this latter procedure. We wish to reconstruct the unit cells upon which the G_1 and the G_2 projections are based. By doing this, the implications of the two settings are made much more evident.

This reversed procedure could be carried out directly from the gnomonic projection, but can be done more easily by using the very closely related reciprocal lattice. In order to establish the unit cell, the vertical boundary planes must be located. But they are parallel to the vertical axis, and their face-poles do not appear in the gnomonic projection. They do appear, however, in the reciprocal lattice, and can be used to locate the unit cell boundaries. The transformation from a gnomonic projection to a reciprocal lattice is very simple, and depends upon the following relationships.

Both the reciprocal lattice and the gnomonic projection are constructed by extending lines from the center of the crystal perpendicular to the crystal planes. In the gnomonic projection all of these lines terminate in the projection plane, giving a two-dimensional array of points. In the reciprocal lattice each line extends a distance which is the reciprocal of the interplanar spacing of the set of planes in question, thus giving a three-dimensional array of points. These points lie in horizontal levels, designated as 0, 1, 2, 3, etc. For a crystal with a simple lattice, the pattern of points in the successive levels is the same, and their respective symbols hk are alike, while l varies with the level.

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[1] Palache, C., *Am. Mineral.*, **5**, 143 (1930).
Parsons, A. L., *Am. Mineral.*, **22**, 581 (1937).
Peacock, M. A., *Am. Mineral.*, **23**, 315 (1938).

The points of a gnomonic projection which represent planes with indices $hk1$ form the basic network of the projection, and have Goldschmidt symbols pq which are integers, with $p=h$ and $q=k$. The $hk0$ planes appear only as direction lines, while all planes $hk2$, $hk3$, etc., appear as points between the nodes of the basic network, and at least one of the symbols pq is a fraction.

The pattern of this basic network is identical in design with the pattern of any level of the reciprocal lattice of a crystal with a simple lattice cell.[2] Accordingly this basic network of the gnomonic projection can be used to represent any level of the reciprocal lattice by merely changing the Goldschmidt symbols pq (integers) to the reciprocal lattice symbol hkl, where $h=p$, $k=q$, and l is the particular level desired. Thus it is possible to go directly from the gnomonic projection of the hexagonal system to the 0-level of the reciprocal lattice (Fig. 1).

The two projections, G_1 and G_2, as defined by Goldschmidt, are illustrated in Fig. 1*a*. The face poles 10 and 11 of G_1 become $\underline{11}$ and $\underline{03}$ in G_2. The face pole $\underline{01}$ of G_2, if present in G_1, would be $\frac{1}{3}\frac{1}{3}$. In these projections the last index, l, is of course equal to 1. If each point in Fig. 1*a* is considered to have a last index of 0 rather than 1, it can equally well represent the 0-level of the reciprocal lattice. This is illustrated in Fig. 1*b*, where the 0-levels of the reciprocal lattices corresponding to the G_1 and G_2 settings are shown.

The distance in the 0-level from any point to the origin is the reciprocal of the spacing of the set of planes represented by that point. By arbitrarily choosing a reciprocal factor, we can reconstruct the unit cells on which the two projections G_1 and G_2 are based. This is shown in Fig. 2. The small unit cell *OABC* is derived from the larger reciprocal lattice unit *ODEF* (G_1), while the large unit cell *OLMN* is derived from the smaller lattice unit *ORDS* (G_2). Thus it is evident that the G_1 projection is based on a simple hexagonal unit cell, *OABC*, and that G_2 is based on a multiple cell *OLMN*, whose cross-section is three times that of *OABC*. The cell *OABC* has its primitive translation a_0^1 in the usual secondary position, while *OLMN* has its primitive translation a_0^2 in the intermediate position. Both cells have the same vertical translation c_0.

---

[2] In centered lattices, because of characteristic absences, successive levels of the reciprocal lattice are different. In non-orthogonal crystals successive levels may have the same pattern, but are shifted horizontally. The above statement says the pattern of the basic projection network is identical in design with that of any level of the reciprocal lattice for a crystal based on a simple lattice. The actual size of the two networks depends upon arbitrary factors. Thus the size of the gnomonic projection network depends upon the radius of the unit sphere, which is usually chosen as 5 cm. The actual size of the reciprocal lattice network can be made identical with that of the projection by an appropriate choice of the reciprocal factor.

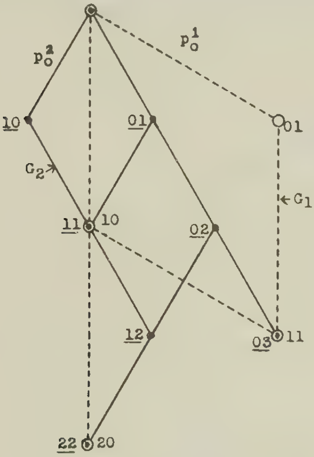

FIG. 1*a*

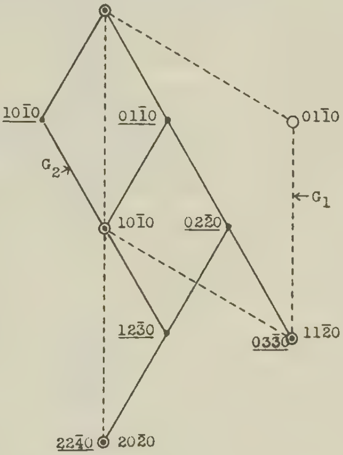

FIG. 1*b*

FIG. 1*a*. Gnomonic projections of the hexagonal system in the two settings, G_1 and G_2. G_1 is shown in dashed lines; G_2 is in solid lines and the G_2 symbols are underscored.

FIG. 1*b*. 0-level reciprocal lattices derived from the two gnomonic projections of Fig. 1*a*.

The axial ratio for the simple cell *OABC* is $c^1 = c_0/a_0^1$. This is the value which would be derived from goniometric measurements in the conventional orientation, hence $c^1 = c$. Thus in Fig. 1*a* the distance p_0^1 is equal to $c_0/a_0^1\sqrt{\frac{3}{4}}$, hence $p_0^1 \times \sqrt{\frac{3}{4}} = c^1 = c$. For the triple cell the axial ratio is $c_0/a_0^2 = c^2 = c/\sqrt{3}$, and in Fig. 1*a* the distance $p_0^2 = c_0/a_0^2\sqrt{\frac{3}{4}}$, and $p_0^2 \times \sqrt{\frac{3}{4}} = c^2 = c/\sqrt{3}$. But in terms of the true unit cell $p_0^2 = c_0/a_0^1 3/2$, and $p_0^2 \times 3/2 = c$.

For crystals based upon a rhombohedral unit cell exactly the same relationships exist. If the rhombohedral cell is referred to hexagonal axes, new points are added at $\frac{1}{3}\frac{2}{3}\frac{2}{3}$ and $\frac{2}{3}\frac{1}{3}\frac{1}{3}$ in the simple cell *OABC*, and corresponding points in the triple cell, but the cell outlines remain unchanged, as do the geometrical relationships involving c^1, c^2 and c, namely $c^1 = c$ and $c^2 = c/\sqrt{3}$.

These relationships differ from those derived by Goldschmidt.[3] His equations relating G_1 and G_2 to c are the same as above, but he introduced values of c^1 and c^2 as follows:

$$(G_1)\ p_0^1 \times 3/2 = c^1 = c\sqrt{3}.\quad (G_2)\ p_0^2 \times 3/2 = c^2 = c.$$

These values of c^1 and c^2 are such that the length of a, taken as unity in the G_1 cell, must be equal to the distance OH (Fig. 2), and in the G_2 cell equal to the distance OA. Obviously OH is less than unity in the cell $OABC$, and hence his value of c^1 is too large; $c^1 = c\sqrt{3}$. It so happens that OA, which is not equal to unity in the triple cell, is equal to unity in the G_1 cell, and hence Goldschmidt's value of c^2 is incorrect for G_2 but correct for G_1, and thus his value of c^2 agrees with the customary value of c. This situation results from the fact that although the axial ratio was derived from $11\bar{2}1$, which cuts at unity on two secondary axes 120° apart, he used the intercepts of this face on the two intermediate axes 60° apart for his unit values in determining c^1 and c^2.

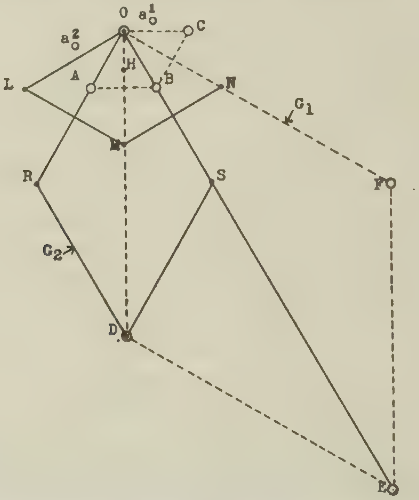

FIG. 2. 0-level reciprocal lattices for the G_1 and G_2 settings, with the unit cells upon which they are based. The small G_1 unit cell *OABC* (dashed lines) gives rise to the large reciprocal lattice unit *ODEF* (dashed lines). The triple G_2 unit cell *OLMN* gives rise to the small reciprocal lattice unit *ORDS*.

The G_1 setting has commonly been used for crystals with hexagonal development, and as used by Goldschmidt did not give the proper value of c. The G_2 setting has been considered more suitable for crystals with a rhombohedral development. As has been shown, the G_1 setting is based on a simple hexagonal unit cell in the customary orientation, and its symbols correspond to the usual Bravais indices. The objection that it does not give the correct value of *c* has no validity. On the other hand, the G_2 setting is based on a triple cell, with a value of *c* different from the customary one, although this fact has not been generally recognized in the past.

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[3] Goldschmidt, V., Index der Krystallformen der Mineralien, vol. 1, 33–35 (1886).

Actually this triple cell is sometimes used in crystal structure descriptions. In certain symmetry groups of the hexagonal system the secondary and intermediate positions do not carry the same symmetry elements, and are therefore distinguishable. For example, in the ditrigonal pyramidal class there are three vertical symmetry planes, and in the usual morphological description of this class, these planes are considered as being in the intermediate positions. But structurally the alternative arrangement, with three planes in the secondary positions, is equally possible, hence the two space groups *C3m*1 and *C31m*. To bring the structural data in harmony with the morphological data in this latter case, the triple cell may be used, for it reverses the intermediate and secondary positions. This convention, however, has no application to rhombohedral crystals, which are always described either in terms of rhombohedral axes, or else in terms of the unit hexagonal cell of the G_1 setting.

The question thus arises as to whether there is any good reason for continuing the use of the G_2 projection. A possible advantage is that it has three times as many nodes in its basic network, and therefore has three times as many possible face-poles for which the Goldschmidt symbols will be integers. This would apply equally to both hexagonal and rhombohedral crystals. Of more significance is the fact that the most prominent $hk\bar{i}l$ zones in rhombohedral crystals coincide with the basic network of G_2 rather than G_1, so that at least one of the Goldschmidt G_2 symbols is an integer, and is common to all faces of the zone.

It would seem that this slight advantage is greatly outweighed by the confusion caused by a dual system, with two orientations, two sets of symbols and indices, and two axial ratios. It is therefore concluded that there is no sufficient reason for retaining the G_2 projection, and that in the future all hexagonal crystals, both with hexagonal and rhombohedral developments, should be described in terms of the G_1 projection.

ACKNOWLEDGMENT

The writer is indebted to Professor M. A. Peacock, of the University of Toronto, who kindly read an early draft of this paper and made several helpful suggestions, and who also heartily concurred in the conclusion that the G_2 projection should be dropped.

NOTES AND NEWS

LUDWIGITE FROM COLORADO GULCH, NEAR HELENA, MONTANA

Adolph Knopf,
Yale University, New Haven, Conn.

The relatively rare magnesium-iron borate ludwigite was found during the past summer to occur abundantly 10 miles west of Helena, at Colorado Gulch, Lewis and Clark County, Montana. It occurs at two prospect pits on the summit of the high hill northwest of the junction of the forks of Colorado Creek. The prospect openings are in the marbleized dolomites and limestones of the Devonian Jefferson formation a few yards from the contact of the Boulder batholith, which here consists of subporphyritic quartz monzonite. The prospect pits had been opened up in search for iron ore, which consists of magnetite having a notably perfect octahedral parting, apparently as a result of incipient alteration.

Large quantities of black rock are exposed, consisting almost wholly of a radially fibrous mineral, which because of the prevalence of tourmaline in this part of the batholith might at first sight be considered to be tourmaline. The silky luster of the mineral and its tendency toward ocherous weathering, however, suggest that the mineral is ludwigite. The identity of the mineral was proved by its boron flame reaction, solubility in HCl, and copious precipitates of iron and magnesium. When crushed and examined in oils, a large number of straight slender fibers are seen, but only the very thinnest of them are translucent. The fibers give sharp, straight extinction, and are pleochroic, from deep olive-green in the transverse position to brown parallel to the length. They have positive elongation, and fibers showing the maximum difference in absorption give flash figures, which show that $Z=c$. By Mallard's method 2E was found to be 40°; the dispersion is powerful, $r>v$. The index $\alpha=1.85$.

The specific gravity, kindly determined by Dr. George Switzer, is 3.70 ± 0.02. As this seemed somewhat low, determinations on ludwigite from the type locality, Banat, Hungary, were made; one specimen (Brush Coll. no. 1082) gave 3.97 ± 0.02, and another (Brush coll. no. 1080) gave 3.70 ± 0.02. Magnesioludwigite (Brush Coll. no. 4172) from the type locality, Big Cottonwood, Utah, was also measured, giving the value 3.62 ± 0.02. The ludwigite from Colorado Gulch is therefore near the magnesian end of the ludwigite series. Like the type material, it is fairly magnetic.

To those familiar with the northern portion of the Boulder batholith and the extraordinary abundance of tourmaline in its marginal zones and in its ore deposits,[1] it has long seemed anomalous that other boron minerals have not developed. Before this ludwigite was found, axinite occurring in small amount at Elkhorn was the only boron mineral other than tourmaline known to be present in the contact zones of the Boulder batholith. Ludwigite, intimately mingled with magnetite and a minor amount of forsterite, was found by Donald F. MacDonald[2] to occur at the Redemption iron mine in the contact zone of the Philipsburg batholith, about 50 miles southwest of the Colorado Gulch locality.

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[1] Knopf, Adolph, The tourmalinic silver-lead type of ore deposit: *Econ. Geology*, **8**, 105 119 (1913); Ore deposits of the Helena mining region: *U. S. Geol. Survey, Bull.* **527**, (1913).

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[2] Schaller, W. T., Ludwigite from Montana: *U. S. Geol. Survey, Bull.* **490,** 28–32 (1911); cf. also Emmons, W. H., and Calkins, F. C., Geology and ore deposits of the Philipsburg quadrangle, Montana: *U. S. Geol. Survey, Prof. Paper* **78,** 129, 162, 220 (1913).

BOOK REVIEW

ELEMENTS OF MINERALOGY by ALEXANDER N. WINCHELL. xiii+535 pages, 468 figures. Prentice-Hall, Inc., New York, **1942.** Price $5.00.

This text attempts to do for the beginning student of crystallography and physical mineralogy what Dr. Winchell's *Elements of Optical Mineralogy* has done for the student beginning in that field, namely: to present minerals as members of broad groups which vary continuously in composition and properties. Most texts permit the student to infer that minerals are fixed in their chemical and mineralogical properties. In this respect, the new text succeeds admirably, since in all discussions the idea of continuous variation and serial relations between properties in isomorphous groups dominates descriptive, illustrative, and interpretive material.

The chapter headings follow a customary pattern: I, Introduction; II, Crystallography; III, Physical Mineralogy; IV, Chemical Mineralogy; V, Descriptive Mineralogy; VI, Economic Mineralogy; VII, Determinative Mineralogy; followed by a glossary and index.

In the chapter on Crystallography, Winchell has succeeded in the reviewer's opinion in making the basic concepts of the *x*-ray study of crystals understandable to the beginner as the basis for the subdivisions of physical crystallography. This is a distinct innovation since texts have clung to the traditional presentation of physical crystallography, followed by a discussion of modern *x*-ray methods. Excellent figures showing the relations between crystal habits and mineral structures in the six crystal systems are particularly useful (pp. 112–113). The discussion of crystal systems follows the conventional Dana order. Illustrations are numerous and well placed.

The chapter on Determinative Mineralogy combines physical and crystallographic properties in a series of four identification tables, each based on a different property or combination of properties. These should prove exceedingly useful since the student has an opportunity to check his identifications by a series of parallel keys, based on different grouping of properties. Table I is based on streak and specific gravity; table II on hardness and streak; table III on cleavage and luster; and table IV on refractive index.

The book is well composed. Errors are few, although some, especially in the section on Chemical Mineralogy, are annoying. For example, selenium (p. 218) is said to have a valence of +2 or +6, and an example, SeO_2, is cited which has the valence +4; sulfur (p. 220) is given as +2 or +6 when in the commonest sulfide minerals and in an example given (H_2S) the valence is −2. Similarly, tellurium is stated incompletely. A few diagrams are mislabelled, especially the line drawings of crystals: figs. 70, 145, 150, and 152, where Miller indices of faces are incorrectly designated. Professor Winchell, however, is to be complimented on a book which should be well received by teachers of mineralogy.

The price of the book ($5.00) may limit its adoptions, since in future use to the geology student as a reference work, it is of somewhat less completeness than other texts in the field, selling at essentially the same price.

ROBERT W. WEBB

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